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de l'Union géodésique et géophysique internationale

Publié par le Secrétaire général

FRANCESCO SIGNORE

Série II — Tome VI

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CONDITIONS DE PUBLICATION

1. **Commission de Publication.** — La Commission de Publication est constituée par le Comité éxécutif de l'Association de Volcanologie de l'Union géodésique et géophysique internationale:

Elections d'Édimbourg, 1936. Président : Prof. A. MICHEL-LÉVY (France) ; V. Présidents : D.r T. JAGGAR (Etats Unis) ; D.r J. E. RICHEY (Angleterre) ; Prof. D.r B. G. ESCHER (Hollande) ; Secrét. général : Prof. F. SIGNORE (Italie).

2. **Correspondance.** — Pour toute communication relative au Secrétariat général de l'Association internationale de Volcanologie et à la rédaction adresser : Prof. F. SIGNORE, Via Tasso, 199. Napoli - (Italie).

3. **Insertions.** — Seuls sont insérés, s'il y a lieu, les articles ayant pour auteurs les Membres des Comités nationaux et des Sections volcanologiques et les Volcanologistes délégués officiels aux Assemblées générales de l' Union, *ou les articles d' autres présentés par ces personnalités.*

Les opinions et théories émises n'engagent que leurs auteurs.

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(Voir la suite à p. 3 de la couverture)

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Pour toute communication relative au Secrétariat général de l'Association internationale de Volcanologie, adresser: Prof. **FRANCESCO SIGNORE,**

Via Tasso, 199 - Napoli - **Italie.**

Téléph. **15749**

Septième Assemblée Générale à Washington

du 6 au 15 Septembre 1939

1e PARTIE

MINUTES OF SESSION OF SEPTEMBER 7, 1939

The first meeting of the Association was opened at 10:30, on the call of Dr. E. G. ZIES, Chairman of the Section of Volcanology of the American Geophysical Union, in accordance with the request of the Executive Committee of the International Union in the absence of President MICHEL-LÉVY.

The following were present :

T. F. W. BARTH, Norway, accompanied by Mrs BARTH ; A. R. V. ARELLANO, Mexico; Jean VERHOOGEN, Belgium ; and from the United States : Francis BIRCH, W. D. URRY, R. W. GORANSON, David T. GRIGGS, Robert BALK, J. J. GLASS, E. F. OSBORN, C. S. ROSS, J. F. SCHAIRER, Earl INGERSON, Michael FLEISCHER, George TUNELL, C. V. THEIS, G. M. HALL, F. E. WRIGHT, E. B. DANE, Jr., Adolph KNOPF, E. B. KNOPF, E. G. ZIES, C. R. LONGWELL, James GILLULY.

The following acting officers, for the conduct of the meetings, were nominated :

Acting-President Dr. L. H. ADAMS.

Acting-Vice-Presidents Dr. E. G. ZIES and Dr. Adolph KNOPF.

Acting-Secretary Dr. James GILLULY.

The temporary officers were elected by acclamation, and Dr. ADAMS took the chair. Dr. ADAMS expressed the deep regret of all that President MICHEL-LÉVY and many other of our most distinguished European colleagues could not be present.

The Secretary announced that the Executive Committee of the International Union had approved the holding of the Assembly for the purpose of presentation of scientific papers only, and that no business matters were to be acted upon.

At the request of the Executive Committee, Dr. ADAMS appointed a committee of two members to examine the accounts of the General Secretary, Professor F. SIGNORE. The committee named was composed of Francis BIRCH and Eugene CALLAGHAN.

T. F. W. BARTH presented a paper entitled, « *Pristine and Contaminated Rock Magma and Thermal Water* ».

There were brief questions asked by E. G. ZIES and James GILLULY, to which the author replied.

Francis BIRCH presented a paper by himself and Harry CLARK, entitled « *The effect of temperature upon the thermal conductivity of rocks, single crystals, and glasses* ».

The author's abstract states : « Measurements of absolute thermal conductivity have been made at temperatures between 0° and 400°C. for a series of carefully selected and analyzed fresh igneous rocks, and for a few metamorphic and sedimentary rocks, single crystals and glasses. Except for rocks composed mainly of feldspar, the conductivity decreases as the temperature increases, the reciprocal of conductivity, or resistivity, increasing nearly linearly with temperature. The conductivity of rocks containing large amounts of feldspar is relatively independent of temperature. The behavior of ' mixed ' rocks is shown to be correlated with their mineral composition and the conductivity of monomineralic aggregates, such as anorthosites and pyroxenites. Conductivities of ultrabasic rocks, given for the first time, are relatively high, approaching the values for quartz. The results are discussed in terms of theories of thermal conduction in electrical insulators ».

The report was discussed by Dr. E. G. ZIES and Dr. F. E. WRIGHT, to whom the author made reply.

Dr. E. G. Zies presented a paper, entitled, « *Surface manifestations of the 1932 eruption of Fuego* ». The author's abstract states :

« The volcano of Fuego in Guatemala is noteworthy on account of the many eruptions that have been witnessed and recorded since its discovery by the Spaniards.

« The eruption of 1932 revealed what the writer believes has been a common characteristic of the explosive extrusion of igneous materials in the volcanic area of Guatemala. No fresh lava was extruded, instead, increasing gas pressure within the throat of the volcano reached the rupture point of the confining plug, exploded, destroyed part of the top, and carried over the rim a great mass of hot, old fragmental material mixed with cold rock torn from the top.

« This mass of hot ejecta was seen to literally flow down the great Barranca Horda. It is now piled up near the base of the upper cone as a haphazard mixture of fine material and coarse subangular blocks varying in size from a few inches on the edge to such as measure six feet or more.

« The explosions was followed by a great pillar of steam, dust, and coarse particles which distributed themselves around the cone and the countryside according to size. The obvious sorting of the material that fell out of the cloud of smoke forms a sharp contrast with the unassorted materials that flowed down the Barranca Horda ».

Mr. A. R. V. Arellano asked the following question :

« Does the finely divided material in the ' Fuego ' eruption represent merely the blowing up or old material from around the crater or is it new volcanic material sprayed out under conditions of high pressure and viscosity ? The occurence of enormous quantities of very pure glass « sand » on the north-east flank of the Tezuitlan massif in Mexico present an analogy which would seem to indicate the latter ».

Dr. Zies replied that he agreed with Mr. Arellano. Dr. Clarence S. Ross also commented briefly on Dr. Zies paper, to which the author replied.

At 12:30 the meeting adjourned.

MINUTES OF SESSION OF SEPTEMBER 8, 1939

The meeting convened at 10.30 with acting Vice-President Knopf in the chair.

The following were present :

Jean Verhoogen, Belgium; T. F. W. Barth, Norway; A. R. V. Arellano, Mexico ; M. Matuyama, Japan; and from the United States : Adolph Knopf, E. B. Knopf, J. S. Burlew, Earl Ingerson, E. F. Osborn, J. F. Schairer, G. W. Morey, O. H. Gish, E. G. Zies, W. H. Bucher, C. S. Ross, George Tunell, D. J. Cederstrom, Eugene Callaghan, C. R. Longwell, F. E. Wright, R. W. Goranson, W. T. Thom, Jr., and James Gilluly.

The chair called upon Dr. J. F. Schairer to read the paper by Dr. A. Rittman, entitled « *The primary alkalibasaltic magma and the origin of ' sial ,* » :

« The author conceives volcanism as a process of degasification of the primary magma which began in praegeologic time and is still continuing. In agreement with T. A. Jaggar he believes the primary magma to be of alkalibasaltic composition unable to differentiate towards a granitic residual melt. On the other hand, the tholeiitic magma type furnishing granitic differentiates is thought to be alkalibasaltic primary magma degenerated by assimilation of sialic material during orogenesis.

« The following hypothesis may explain the formation of the first « sial », notwithstanding the atlantic character of the magma, the origin of the three layers of the continental crust and the source of volcanic energy :

« The molten globe had once a heavy atmosphere formed by all substances volatile above about 400° C. Currents of convection prevented the magma from differentiation. The first crust of consolidation thus consisted of alkalibasalt and was soon subjected to superficial decomposition by the action of the atmospheric vapors. After cooling and condensation of the water, the products of alteration were carried to the primary oceans where they built up the first sediments enriched in radioactive substances. This caused the thermal gradient to be higher under the primary oceans than in the alkalibasaltic primary continents. The basaltic layer under the first sediments began to melt from beneath. The sediments became metamorphosed by heat and volatile substances supplied by the rising magma in the depths. Migmatitisation and partial refusion took place. The mobilized sialic materials migrated upwards forming the upper « granitic » layer of the crust. The residue of the transsudated sediments remained in the intermediate layer, whilst the lower layer consisted of more or less metamorphic alkalibasalt. In the meantime, the isostatic equilibrium was disturbed. The lighter « sialized » sediments rose above the sea level, and the primary oceans became thus the nuclei of our sialic continents. The homogeneous alkalibasaltic crust of the primary continents sunk and was invaded by the sea and formed our actual oceans. These events are called « isostatic inversion ».

« The uplift of the sial was accompanied by an influx of magma in deeper regions. Geosynclinal furrows developed on the border of the rising continents. There the same events happened as under the primary oceans, and probably formed the main source of energy for orogenesis. During the geosynclinal stage, volcanism of primary basaltic magma, more or less contaminated by assimilation of sial or sediments, took place. In the stage of folding no superficial volcanism occurred, but metamorphism and anatexis developed to a great extent. Large plutonic bodies of acid rocks of migmatitic origin were formed. The mountain chain rose to reestablish isostasy. During the last movements hybrid and syntetic magmas of pronounced pacific character may come to the surface along extensive fracture planes.

« In praegeologic time a certain amount of gases and especially of water remained dissolved in the molten magma under the pressure of the heavy atmosphere (about 300 atm). When condensation began, the gascharged magma was yet protected by the crust of consolidation. Discharges of gases happened only where the pressure was lowered by fracturing of the crust, besides gases were lost in orogenic belts by distillation. Nevertheless, still today the primary alkalibasaltic magma is oversaturated for surface conditions. In the residual melts differentiated from primary, syntetic or hybrid magmas, the gas content even increases considerably. Late orogenic continental volcanism is therefore much more explosive than the primary volcanism of the oceanic islands ».

Dr. BARTH commented as follows :

« While I shall take no stand for or against Dr. RITTMANN's main idea about the ultimate cause of volcanism being gas discharge in a (primary) magma, I want to offer the following comments in favor of his maintaining that the primary magma was of alkalibasaltic composition, and that sub-alkaline magmas developed through sedimentary control by assimilation of sialic material during orogenesis.

« In a Niggli concentration tetrahedron (the corners of which represent *al*, *fm*, *c*, *alk*) the projection points of various plateau basalts and alkaline basalts of, e. g., the Hawaiian type and similar rocks, will arrange themselves approximately in a plane that corresponds to the phase boundary separating those magmas that precipitate plagioclase first from those magmas that precipitate pyroxene as primary phase.

« If sub-alkaline magmas developed from these basaltic magmas essentially through fractional crystallization, the line of development would lie in the phase boundary. But the projection points of sub-alkaline magmas (as represented by sub-alkaline basalts, andesites, etc.) markedly depart from this position and actually lead directly into those parts of the Niggli tetrahedron that are occupied by sedimentary (argillaceous) rocks. This indicates to me that the sub-alkaline rock suites (equal to pacific rock suits) as we find them, e. g., in the circum-Pacific zone of folding were formed from primary alkaline basalt magmas through assimilation of sedimentary material in the depths of the geosynclines ».

J. F. SCHAIRER's comment on Dr. RITTMAN's paper was:

« At the Geophysical Laboratory of the Carnegie Institution of Washington, experiments are now in progress bearing on the problem of the role of assimilation in igneous rock genesis. The two quaternary systems, CaO-MgO-Al_2O_3-SiO_2-and CaO-FeO-Al_2O_3-SiO_2 are under investigation. It is hoped that in a few years equilibrium data on silicate compositions will be available. This will enable us to examine both the laboratory and geological field observations in order to ascertain what part assimilation of sediments and older igneous and metamorphic rocks plays in rock genesis and the magnitude of the heat quantities involved in the process ».

Dr. VERHOOGEN made the following comment :

« Dr. RITTMANN states that volcanic activity at the present time might result from the degasification of a primary magma that was once subjected to atmospheric pressures as high as 350 or 400 atmospheres. The question arises as to whether there is sufficient evidence that magma is saturated with respect to normal conditions (temperature around 1100° C., depth of, say, one or two miles). In other words, is it not possible that the gas discharge at volcanoes might be the result of crystallization at, or near the surface, *after* the magma has been erupted ? In such a case, momentary saturation as the lava cools at the surface would be a result of the eruption and not, as RITTMANN believes it to be, its cause ».

Dr. J. S. BURLEW replied that the pertinent factor is whether the magma contains more volatile constituents than correspond to saturation under the present atmospheric pressure, and it need not have been saturated at the previous higher pressure.

Dr. E. G. Zies inquired whether basalts are commonly found within a rhyolitic cone, to which Dr. C. S. Ross replied in the negative. Dr. Zies called attention to the existence of basalts within the rhyolitic cone of the volcano of Batou on Bali. If there are rocks of intermediate composition, they are now covered by the later basalts.

Dr. Callaghan then made the following comment :

« With reference to the occurrence of basalts with rhyolites and other lavas : in the Marysvale area in southwest central Utah, all the lavas are characterized by an equivalence of soda : potash. The great bulk of the lavas are latites and rhyolites. The last eruptions have been olivine-bearing basalt, which also contains equivalent soda and potash. It is also suggested that the basalt is a differentiate of a monzonitic magma as postulated by Gilluly rather than a representation of the basaltic substratum ».

Comments were also offered by G. W. Morey, L. H. Adams, and James Gilluly.

The paper by President A. Michel-Lévy, entitled, « *Emploi des explosifs pour la synthèse par pneumatolyse des minéraux des roches de profondeur (granite). Métamorphisme artificiel* » was read by Acting-President Leason H. Adams.

Abstract — « Production artificielle de minéraux par la pneumatolyse, à l'aide d'explosifs. Enseignement à en tirer pour expliquer la génèse des minéraux dans l'éruptivisme profond et dans le volcanisme ».

« On a couramment recours, pour expliquer la génèse des minéraux des roches de profondeur et des roches effusives, à la notion de déplacements d'éléments à l'état gazeux (pneumatolyse), ou à l'état liquide (magmas), ou à l'état solide (métamorphisme thermique).

« Des expériences sur les explosifs brisants et leurs effets lumineux intenses m'ont conduit à la mise au point d'une technique nouvelle, la micropyrotechnie, par laquelle

je suis parvenu à me servir des hautes températures et des hautes pressions développées au moment de la détonation pour porter des corps mis en mélange avec l'explosif à des états gazeux comparables à ceux devant exister dans les nébuleuses ; le recuit pendant quelques jours, à des températures relativement basses et sous pression, de ces gaz, a permis la cristallisation d' un certain nombre d' espèces cristallines.

« Les données ainsi recueillies sont fort instructives pour venir à l'appui des hypothèses sur la génèse de certains minéraux du granite, des remplissages filoniens (aplites et pegmatites), et la génèse des minéraux de fumerolle dans le volcanisme, par les effets de la pneumatolyse ».

Dr. Burlew commented as follows :

« Professor Michel-Lévy's novel experiments on artificial metamorphism seem adequate to support his conclusion that new minerals can be formed in rocks under the influence of steam and other hot gases without actual remelting ; but I do not think that he has proved conclusively that a pressure as high as 3000 to 4000 kg./cm.^{2} is necessary for this process or for the direct synthesis of minerals by « micropyrotechnics ». Since the gases of detonation represented all the products of the 1.5 g. of explosive, and since they contained 25 % of water (presumably by weight), the bomb cavity of 4 cc. contained 0.37 g. of water, which at 500° C. would have had a partial pressure of only about 250 kg./cm.^{2}. This relatively low steam pressure was sufficient to promote the synthesis of orthoclase and albite from silica, alumina, and alkali carbonate. In order to find out whether the additional pressure resulting from the other gaseous products of the explosion is essential, the following experiment might be performed. Detonate a mixture of silica, alumina, and alkali as had been done in the test experiment to determine the effect of the detonation itself. In that experiment this procedure had yielded a glass. To the bomb containing such a glass add 0.37 g. of water, reseal the bomb, and heat it at 500° C. for the usual length of time. If crystals of feldspar are obtained, they

would indicate that the high pressure of the confined explosive gases is without significant effect on the mineral synthesis, and that only pressure necessary for the crystallization is that of the steam ».

Drs. Morey, Ross and Schairer also commented upon the paper, regretting that isolated experiments of the type described could not hope to outline the fields of existence or of formation of mineral phases in the earth. Only systematic investigations of long ranges of temperature, pressure and composition can be expected to furnish data of exactness adequate to modern petrologic and volcanologic work.

At 13:00 the meeting adjourned.

MINUTES OF SESSION OF SEPTEMBER 9, 1939

The meeting was called to order by Acting-President L. H. Adams at 10:00.

Present were :

A. R. V. Arellano, Mexico ; T. F. W. Barth, Norway ; A. E. Benfield, England : Jean Verhoogen, Belgium; Eugenio Sotomayor, Mexico ; and the following from the United States : E. B. Dane, Jr. R. Miller, G. W. Norey, George Tunell, Eleonora B. Knopf, Adolph Knopf, Earl Ingerson, E. G. Zies, K. J. Murata, T. Sfadnichenko, J. W. Greig, E. Callaghan, J. F. Schairer, C. S. Ross, J. A. Crocker, James Gilluly, O. H. Gish, Mrs. O. H. Gish, Eleanor Gish, Helen Balk, J. J. Glass, E. F. Osborn, King Hubbert, W. C. Krumbein, A. L. Day, Paul G. Ledig, D. C. Fahn, V. F. Hess, F. E. Wright.

A request from the Association of Hydrology for the consideration of a jointly sponsored discussion of Hot Springs by that Association and this, to be held at the next International Assembly was received. After favorable informal comment from several persons, Adams appointed Barth to draw up a resolution embodying the approval of this Association of the proposal.

The President introduced. Dr. Jean VERHOOGEN, who delivered a paper entitled, « *New data on the mechanism of eruptions of Hawaiian type* »:

« On January 28, 1938, an eruption broke out at Nyamlagira, an active volcano in the Virunga Range, north of Lake Kivu (Western Rift Valley, Africa). The activity that existed in the crater and which included numerous small lava lakes of Hawaiian type shifted to a place called Tshambene, at the southwestern foot of the mountain. The eruption has lasted for more than a year, and at this time (June, 1939) there are no signs yet that it may stop. A summary of events up to October, 1938, is given, together with the results of temperature measurements, spectrographic analyses of the flames, and estimates of the gas discharge. The amount of gases discharged is very low compared to the amount of lava. The rôle of gases in eruptions of this type may be less than is usually believed ».

OSBORN asked, « How does the speaker explain the fluctuation of level of lava lakes ? The first stage or sinking of lava could not be due to displacement of gases if the volume of gas is as small, relative to the volume of magma as the speaker stated. Is it a hydrostatic phenomenon related to lava movements in other lava lakes or fissure flows or cones ? Are the lava lakes at the same altitude ? »

VERHOOGEN replied that the level of the lava in any single lake was independent of activity at other points. Fluctuations in level are apparently independent of gas activity as the gas appears either before or after the sinking of level. They are still unexplained. The lava lakes are at the same altitude.

BENFIELD inquired how high were the temperatures measured. VERHOOGEN replied that they ranged closely around 1100° C.

Remarks were also made by MOREY, ZIES, and GISH, to which the author replied.

The Acting-President called upon E. G. Zies, who delivered a paper on « *A coordinated study of volcanic phenomena at Santa Maria* ».

(a) E. G. Zies — « *Outline of plan and geochemical work* ».

Abstraet — « In 1902 an eruption of great intensity on the volcano of Santa Maria in Guatemala revealed only too clearly that potentially active igneous materials were present in the supposedly extinct volcanic edifice. No further activity was noted until 1922 when without any of the usual spectacular manifestations the present new dome of Santiaguito made its first appearance. Within a period of three years this dome was built up to a height of 1,000 feet by the extrusion of igneous materials and had become a conspicuous feature in the landscape.

« No consolidated flows of lava have issued up to the present time ; the lava is extruded as a hot plastic mass which solidifies almost at once on emerging. In 1929 an explosion covered the surrounding terrain with clastic rock. The activity since this year is characterized by the extrusion at times of cliff and needle like formations and at times by the intermittent but persistent extrusion of hot clastic andesite, which is an important factor in increasing the bulk of the dome. This extrusion has not persisted in any one portion of the dome; at times it appears at the top of the dome, at other times the scene of activity shifts around the periphery. The activity is furthermore characterized by the presence of fumaroles at the top and on the eastern slope. Steam and acid gases are constantly being emitted and their temperature ranges from 90° C. to 450° C., or even higher.

« In the study of volcanic activity, attention has heretofore been of necessity confined to the outward manifestations which, in spite of their spectacular character, are only one stage of the work done by the volcano. It seems distinctly worth our while to supplement geochemical studies with studies in which attention is focussed on the activity within the volcano that precedes and follows an eruption. In 1932 and 1935 the writer visited the dome of Santiaguito and was impressed with the fact that we have an unusual opportunity for studying the continuing activity at this very young igneous manifestation not only by the geochemist but also by the geophysicist. Modern geophysical methods which take into consideration the physical characteristics of the material below the surface seem to give most promise of success in enabling us to make inferences with respect to physical discontinuities that may exist below the surface. Such a preliminary cooperative study was undertaken in the first three months of 1939 by two laboratories of the Carnegie Institution of Washington, namely, the Geophysical Laboratory and the Department of Terrestrial Magnetism.

« The preliminary chemical studies revealed that the volcanic dome of Santiaguito is composed of a porous, glassy hornblende andesite which forced its way through the older materials of the parent volcano, Santa Maria. The acid gases and steam escaping from the fumaroles are producing considerable alteration of the extruded rocks. This is not at all surprising when we learn that the dominant acid gases are sulfur dioxide, sulfuric acid, and especially hydrofluoric acid, which has been found in notable amounts not only at Santiaguito but also at the volcano of San Miguel in El Salvador and seems to be characteristic of the volcanic area of Central America. It is quite possible that the destructive action of the acid gases is an important factor in providing channels of more ready egress for the potentially active lava within the edifice ».

(b) P. H. Gish — « *Initial geoelectric work* ».

« Various kinds of chemical and physical activity in the Earth are potential sources of geoelectric phenomena. For example, the electric « halo », so to speak, of certain sulphide ore-bodies has led to the discovery of such deposits of ore. Thus far observations indicate that in mountainous regions rather large differences of potential exist between two points on the Earth's surface, provided these are situated at different elevations, the higher point being generally at the lower potential. Investigations, made in the Department of Terrestrial Magnetism, indicate that this effect is not attributable to superficial circumstances but probably arises from relatively deep-seated process. Furthermore, PALMIERI reported an apparent relation between the change in such potential-differences and the volcanic activity of Vesuvius.

« These statements suggest some reasons for thinking that one or another phase of volcanic activity may have associated electrical manifestations which, when adequately observed, may serve to indicate the position of the volcanic activity and to compare the intensity of the activity at one time with that of another.

« To ascertain whether these expectations can be realized, was an objective of the geoelectric work done in the vicinity of the Volcano Santa Maria through cooperation of the Department of Terrestrial Magnetism of the Carnegie Institution of Washington with the Geophysical Laboratory of the same Institution.

« The work consisted of two parts, namely : (a) Potential-surveys in which the difference of potential between two points on the surface of the Earth was measured from place to place in a chosen area and in such a way that lines of equal potential could be charted for the area ; (b) continuous registration of the difference of potential between two pairs of points on the Earth's surface. Whenever feasible, one of the pairs was selected so as to lie on a north-south line, the other so as to lie on an east-west line. These registrations provide the data needed for ascertaining the changes with time of both the intensity and direction of the potential-gradient in the Earth.

« A thorough *potential-survey* was made over the floor of the crater of Santa Maria. Minor surveys of this type were made on the southerly slope of the dome, known as Santiaguito, around the hot springs in the general vicinity of the village of Zunil, and over other formations near Quezaltenango. These are to be regarded as reconnaissance-surveys. A discussion of the significance of the data obtained in these surveys will be possible only after further study. However, at this stage it can be stated that some well-marked characteristics are manifested, particularly in the survey of the crater-floor. There the most general feature in the distribution of potential is, that near the active dome, Santiaguito, the potential is generally greater than at more remote positions.

« *Continuous records* of two components of the earth-potential gradient for 37 complete days were obtained in the vicinity of the camp on the southwest flank of Santa Maria, namely, on the side toward the Pacific Ocean, at an altitude of about 6500 feet above sea-level. After breaking camp, similar registrations were made for the duration of a week at each of two other places, namely, (a) at Finca *El Faro*, a coffee-plantation, about 6 km south-southwest of the camp and at 4000 feet lower elevation, and (b) at Finca *La Foresta*, in the outskirts of Quezaltenango, about 11 km to the northeast of the Volcano Santa Maria at an elevation of 8000 feet.

« The outstanding feature of the records obtained at these places is the large amplitude of the variations. Thus, while the general character of the diurnal variation of the earth-potential gradient at all three places is similar to that found at a number of other places on the Earth, yet at Santa Maria and El Faro the diurnal range (range of the graph for the mean diurnal-variation) is nearly 100 times that found at Watheroo, Western Australia and is about three times the extraordinarily large range reported from the Ebro Observatory, Tortosa, Spain. Although the diurnal range at La Floresta is much less than at the other Guatemalan stations, it is nevertheless large relative to that found in the observations at all other places, except the Ebro Observatory. where a range of comparable magnitude is observed. Irregular variations at these Guatemalan stations also have unusually large ranges. For example, at Santa Maria, most of the records show one or more excursions having a duration averaging about one-half hour and a range of 100 mv/km or more. Some of these are universal, instead of local phenomena, since they can also be identified in records obtained simultaneously at the United States Coast and Geodetic Survey Observatory, Tucson, Arizona, and at the Carnegie Institution of Washington Observatory near Huancayo, Peru. That some of the irregular variations are of purely local origin and possibly associated with some aspects of volcanic activity at Santa Maria is little more than a surmise at the present stage of the study, but it is hoped that after these records have been more thoroughly analyzed and compared with the records obtained simultaneously at Tucson, Huancayo, and Watheroo, it will be possible to reach a definite conclusion. However, since it has been found that the records obtained in Guatemala contain a prominent « background », provided by the general system of earth-currents, this hope may not be realized in the study of the limited data obtained on this expedition. Because of the prominent background of universal effects, it will be desirable in future work of this character to obtain simultaneous registrations at several places in the vicinity of the volcano, so that if there are geoelectric variations associated with the activity of the volcano these may be more readily distinguished from the other variations by the manner in which they depend upon position.

« The large range in the diurnal variation, ad in other variations derived from the general system of earth-currents, is doubtless of interest for volcanology, in that it probably indicates a very high electrical resistivity of the structure to depths of some kilometers, near the volcano and on the Pacific slope, even though the overburden, as indicated by rough tests, has relatively low resistivity, whereas near Quezaltenango, in the valley of the Rio Samalá, the low-resistivity overburden apparently extends to considerable depths.

« It is important to volcanology to ascertain whether there are geoelectric variations which are associated with volcanic activity, chiefly because, if such an association is found, registration of the geoelectric variations would provide a continuous index to volcanic activity ».

(b) A. G. McNish — « *Initial geomagnetic work* ».

« Investigations of volcanic activity have been confined largely to the surface-aspects of the phenomenon. Volcanologists have perforce contented themselves with examination of the ejected materials — solids, liquids, and gases — and have endeavored to infer from the physical and chemical states of those materials what subterranean processes led to their ejection. From configurations of the surface and comparison with partially eroded extinct volcanoes they have endeavored to infer the sub-surface distribution of potentially active material.

« During recent years geophysical methods for determining subsurface structure have come into practice. These methods interpret the structure from the magnetic and gravitational fields which they produce and their ability to transmit or reflect seismic waves and to conduct and produce electric currents. Any method of geophysical interpretation encounters unusual difficulties in volcanic regions because of the unusual complexity of volcanic structures.

« Among the most promising of such methods is the magnetic, because the magnetic properties are most likely to be differentiated between hot (and therefore potentially active) rocks and cold rocks. By means of the magnetic method the presence of any extensive lava-chamber should be detectable and its depth and extent inferred. The magnetic method should also give evidence of a close approach of hot material to the surface and thus suggest seats of subsequent activity.

« During the past year an Expedition was sent by the Geophysical Laboratory and the Department of Terrestrial Magnetism of the Carnegie Institution of Washington at the suggestion and under the leadership of Dr. E. D. Zies to ascertain if such methods could be applied in the study of the volcanic region of Guatemala, Central America. The work of the Expedition was confined to the region around the volcano Santa Maria.

« Present volcanic activity in Guatemala occurs along a belt about ten km wide, which roughly parallels the Pacific Coast approximately 50 km inland. The Pacific side of this volcanic rift slopes steeply toward the coastal plain, an elevation of less than 300 meters being reached over 40 km from the coast. Inland, an extensive plain of pumaceous material covers the trough behind the volcanic belt. The depth of pumaceous material probably averages hundreds of meters. The plain itself lies at an elevation of some 2000 meters, while the cones of the volcanoes attain an elevation around 3500 meters. Here and there, nestled between individual cones, are found less extensive plains of pumaceous material at altitudes of nearly 3000 meters. Although topography across the volcanic rift is extremely rugged, most of the exposures are of pumaceous material except where deep cuts have been made by small streams.

« The most violent eruption in this region during recent times occurred when the volcano Santa Maria blew away its entire flank on the Pacific side in a series of explosions in 1902. In 1922 activity was resumed in the crater left by the explosions. Within a few years a new cone — known as Santiaguito — was built up; it has now attained a height of over 600 meters above the original floor of the crater. To the northwest of Santa Maria lies another volcano which was active within the past couple of centuries, while to the northwest lies a more ancient volcano. The entire region in this vicinity is filled with hot springs, fumaroles, and other evidences of thermal activity.

« The magnetic work of the Expedition consisted of a survey of the region around this center of volcanic activity. Observations of vertical magnetic intensity were made along the highways, side-roads, and paths. Four hundred and forty-nine stations were occupied, using an Askania vertical-intensity balance of the Schmidt pattern. At 50 of these stations observations of horizontal intensity with a quartz-fiber horizontal-intensity magnetometer (QHM) of la Cour type and observations of declination with a magnetometer and theodolite of Carnegie Institution of Washington type were also made. Relative values of vertical intensity were referred to a station on the outskirts of Quezaltenango.

« Stations were spaced at intervals of approximately one km along the roads. Various key-stations were located by triangulation or by association with known surveyed points ; intermediate stations were located with reference tho these by measured distances and approximate directions. The difficulty of establishing many of these stations need not be discussed. In places it was necessary to cut foot-trails through underbrush and to climb very steep slopes with the equipment.

« Sufficient data for a satisfactory geophysical interpretation of the region could not be obtained in the limited time available for the survey. However, certain distinctive features of the region were revealed which suggest the dominate features and indicate the directions future work should follow. A typical profile across the volcanic rift was displayed. This profile applies across the rift along the main highway from the northeast to the southwest. Its characteristic features are revealed in surveys along other highways.

« Distribution of volcanic activity along this cross-section is vividly reflected in the magnetic profile. Across the volcanic rift low values of vertical intensity predominate. On the Pacific slope of the rift vertical intensity averages about 1500 gammas higher than in the center of the rift. The exposed rocks along the cross-section where low values of vertical intensity were obtained were highly magnetic and gave rise to large variations from station to station. However, when the average values at several near-by stations were obtained, definitely low values resulted, suggesting that vast quantities of the underlying material is non-magnetic and hence at high temperatures. It seems likely that the extent of this hypothetical material in the vertical direction and along the direction of the cross-section exceeds ten km.

« Thus the magnetic data indicate the presence of a magma-chamber beneath the rift with dimensions comparable to the width of the rift. Possible extension of this chamber along the longitudinal axis of the rift cannot be discussed from the data so far obtained although this may be inferred from the general topographic and volcanic features of the region.

« Another question of considerable interest upon which the magnetic data supply some evidence concerns the extent to which individual superficial centers of volcanic activity are independent. While a definite answer to this question is not supplied by the data, they suggest that the centers have nothing in common to a depth of perhaps several kilometers but that they all are a part of the general trough of the volcanic rift. More definite conclusions on this subject must await detailed areal surveys.

« The purpose of the magnetic work which has been undertaken was to determine the applicability of magnetic methods to the volcanic problems of the regions. There seems little doubt in view of these preliminary results that magnetic methods of investigation will produce valuable information for the interpretation of the volcanic phenomena, for they have already yelded pronounced indications of the general structure.

« How far magnetic methods may go toward achieving the main practical purpose of volcanological research — prediction of actual eruptions — is purely conjectural. While there seems no hope of forecasting dates of eruptions from magnetic measurements at the present time, they may be helpful in indicating close approaches of potentially active material to the surface and hence suggest where future outbreaks of activity are probable.

« The Expedition is greatly indebted to the Gulf Research and Development Company for two Askania vertical-intensity balances and appurtenances which were generously loaned for use on this survey ».

Arellano stated that it seems that the magnetic profiles extended northward past the volcanoes sufficiently so that a stronger rise in magnetic intensity should be noted, although, of course, the lessening magnetic intensity in this direction due to latitude must be discounted. As the profile rises towards the south, it might indicate a series of dikes and sills rather than the contrast between the hot volcanic material and the cooler encasing rock.

McNish replied that the northward increase accords with what is known of the latitude effect ; the southern profile may be subject to reinterpretation with the procurement of further data.

Benfield asked whether the density difference between the material of the melted rock reservoir and the surrounding solid rock would make it profitable to cover the same ground with gravity measurements.

McNish asked G. E. Wright to comment on this. Wright remarked that the absence of good topographic maps and the heterogeneous character of the thick pyroclastic rocks that form the surface materials make the region a difficult one in which to attempt accurate gravity work of the type that would seem to be required.

At 13:00 the meeting adjourned.

MINUTES OF FIRST SESSION OF SEPTEMBER 11, 1939

The Association of Volcanology met at 10: 00 a. m., acting Vice-President E. G. Zies presiding.

The following were present :

J. Verhoogen, Belgium ; A. R. V. Arellano, Mexico ; and from the United States : C. S. Ross, J. F. Schairer, Earl Ingerson, Eugene Callaghan, J. W. Greig, James Gilluly, T. Stadinchenko, J. J. Glass.

The following papers were presented :

S. I. Tomkeieff — *The basalt lavas of the Giant's Causeway district of Northern Ireland.* Presented by C. B. Hunt in the absence of the author. Authors abstract:

« The famous columnar basalt lava forming the Causeway, while it belongs to an upper series of olivine-free tholeiitic basalts, projects seawards at the base of high lava-cliffs at the level of and in contact with a lower series of olivine-dolerite lavas. Its anomalous position is explained by supposing that the lowest flow of the columnar upper series filled a river-valley excavated in a thick interbasaltic series of laterites and the underlying lower basalts. Suggestions are made in regard to the terminology and mode of formation of the remarkable columnar structures. A petrographical description, together with a number of chemical and modal analyses, is given, and the petrogenesis of the lavas is discussed ».

The paper was discussed by Ross, Greig, Hunt, Callaghan, and Gilluly.

E. G. H. Blyth — *The nomenclature of pyroclastic deposits.* Presented by C. S. Ross in the absence of the author.

Ross stated :

« The nomenclature of pyroclastic materials proposed by Blyth seems simple and quite acceptable. I am in agreement with a remark by Zies that a nomenclature should not be used to avoid detailed description. It is a useful part of a description but is not a substitute.

« Flow breccias are perhaps on the border line between flows and pyroclastic materials, but some are so obviously clastic in character that « flow breccias » might well be mentioned in the classification ».

The paper was also discussed by Zies, Greig, Gilluly, Callaghan, Arellano.

J. E. Richey — *Association of explosive brecciation and plutonic intrusion in the British Tertiary igneous pro-*

vince. Presented by E. Callaghan in the absence of the author.

Authors abstract :

« An epitome, with examples, dealing, with : (1) the alternating sequence of plutonic intrusion ad explosive brecciation in the various plutonic districts and the magmas concerned ; (2) an inference that, in districts where a series of explosive periods is demonstrable, the situation of the explosions became more deepseated as time went on ; (3) a suggestion that a distinction may be made according to whether the brecciation preceded, accompanied or followed the appearance of the magmatic carrier at the particular level corcerned ».

E. B. Bailey — *Report on British vulcanological research during the period September 1936 - August 1939.* Read by J. F. Schairer in the absence of the author.

N. H. Fisher — *Note on the vulcanological observatory at Rabaul, New Britain, Australian, Mandated Territory.* Read by J. F. Schairer in the absence of the author.

W. Q. Kennedy — *Map of the Active Volcanoes of the World.* In the absence of the author, Gilluly announced the activity of this project. Unfortunately the map had not been received and could not be displayed. In the absence of the map the symbols used on it could not profitably be discussed.

The meeting adjourned at 12:45.

MINUTES OF SECOND SESSION OF SEPTEMBER 11, 1939

At 14:30 the meeting was called to order by acting Vice-President E. G. Zies.

The following were present :

D. la Cour, Denmark ; Jean Verhoogen, Belgium ; and the following from the United States : J. P. Marble,

J. F. Schairer, C. R. Ross, James Gilluly, George Tunell, J. J. Glass, R. E. Stevens, J. W. Greig, E. G. Zies, Earl Ingerson, E. F. Osborn, J. S. Burlew, L. C. Graton, Michael Fleischer, Eugene Callaghan, Jean Verhoogen, D. la Cour, M. Schmehl.

Acting Vice-President Zies introduced Acting President L. H. Adams, who expressed the regret of the Assembly that President Michel-Lévy could not be present. He also expressed his own gratification at the honor of presiding in the stead of President Michel-Lévy. He then read, in English translation, the Presidential Address of President Michel-Lévy, entitled « *Emploi des explosifs pour la synthèse par pneumatolyse des minéraux des roches de profondeur (granite). Métamorphisme artificiel* ».

At the conclusion of the address, D. la Cour, President of the International Union of Geodesy and Geophysics, spoke as follows :

« Having listened to the address of President Michel-Lévy, read by Dr. Adams, I beg to express the thanks of the audience to Dr. Adams. The questions treated in this address are of such importance to all who deal with the structure and physics of the earth that I beg Dr. Adams to convey to President Michel-Lévy the heartiest thanks of the whole of the Union for his address, and to express to him our admiration for the experiments he has carried out in order to elucidate the genesis of the minerals of our globe ».

These sentiments were approved by acclamation.

At 15:15 the meeting was adjourned.

MINUTES OF MEETING OF SEPTEMBER 12, 1939

At 10:00 the meeting was called to order by acting Vice-President Zies.

Present were:

E. Gaviola, Argentina; A. Rojas, Mexico; A. R. V. Arellano, Mexico; P. C. Sanchez, Mexico; T. F. W. Barth, Norway; Graciela Amescua, Mexico; and the following from the United States : C. S. Ross, W. T. Schaller, G. Tunnell, E. F. Osborn, J. F. Schairer, J. S. Burlew, F. Schmehl, M. Fleischer, G. W. Morey, L. C. Graton, Jewell Glass, R. C. Wells, R. E. Stevens, E. Callaghan, F. E. Wright, J. W. Greig, Wilbur A. Nelson, Robert F. Griggs, Robert B. Sosman, Earl Ingerson, J. F. Bell, James Gilluly, E. G. Zies.

The secretary announced the programs for September 13 and 14.

T. F. W. Barth presented a resolution in reply to the inquiry from the Association of Hydrology suggesting that the title of the proposed question for the 1942 meeting be *Geology, chemistry and hydrology of thermal springs*. It was moved and seconded that the resolution be adopted and the secretary was instructed to transmit it to the Association of Hydrology.

L. C. Graton then presented his paper entitled « *The nature of the ore-forming fluid. An analysis of recent opinions* ».

« The nature of the solutions that form metalliferous veins is a problem both geological and physico-chemical, and has long interested workers in each of those fields. Recently it has had attention from investigators skilled in both fields. Their results, supporting magmatic origin of the fluids, are richly illuminating in a variety of respects ; but are still in some degree mutually conflicting. The present analysis seeks to distinguish what appears established from what seems yet controversial. Specifically, the following sub-questions are considered : timing and mechanism of separation from the magma ; motive power for transport ; and nature of the fluids, whether liquid or gaseous, and whether alkaline or acid ».

Schairer said, « I would like to enquire of the speaker, what he understands by the term « alkaline » solutions as applied to his use of that term in reference to the solutions from magmas. Does he mean rich in the alkalies ?

For example, would a solution rich in soda and potash, which also contained fair amounts of fluorine and chlorine be an « alkaline » solution ? ».

Graton replied that he believed he was using the terms in the sense of most earlier writers, such as Fenner and Bowen. It is unlikely that the quantities of halides required to balance the soda and potash of ore bodies could have excaped without leaving more traces than are formed.

T. F. W. Barth commented as follows :

« Synthetic studies of ore minerals and of ore parageneses may be important in solving the question of the chemical environment of natural ore deposits. I may mention that Dr. Jensen of the University at Oslo has shown experimentally that some of the ore minerals at Kongsberg (including the famous « Thread silver » that formerly was believed to have formed from a gas phase probably were formed from aqueous solution at a low temperature (around 130°). I would like to ask whether similar synthetic studies have been made in this country ».

R. C. Wells remarked :

« In this elaborate paper Dr. Graton repeatedly uses the terms acid and alkaline. We are of course all familiar with the distinction under ordinary conditions, as expressed by the pH scale. At higher temperatures, however, there seems to be some question of the applicability of the pH conception; in fact it has not really been studied. At higher temperatures the terms are probably used in a different sense ; alkaline may be used with reference to composition, for example to distinguish from alkaline earths or from silica. At high temperatures silica becomes a strong acid in one sense, it will displace other acid groups. In view of these facts, it would seem desirable to define the terms anew or to use such terms as sodic, calcic, silicic or sulphatic.

C. S. Ross stated, « It is very unfortunate that Bowen is not present. However, reading Bowen's paper, and personal discussion leads to the belief that his main object was to outline a mechanism by which acid solutions could develop. The application was sketchy and the determination of the extent to which such a gas phase is applicable is largely a problem for the geologist. Bowen's views are probably not so far from those of the field geologist after all.

« The term « alkaline » should be used only in the chemical sense, to imply an excess of alkali ions. Where merely the presence of alkalies is implied without reference to the « alkalinity », the term « alkalic » should be used. Thus s soda or potash rich feldspar is alkalic, but is definitely not alkaline; and the same applies to rocks, magmas and solutions. In the same way, « silicic » rather than « acid » should be used for a rock or magma rich in silica, and « basic » should be avoided. In other words, the geologist has no right to appropriate terms that have long had a definite meaning to the chemist, and distort that meaning. Former misusage is not justification for its continuance ».

Ingerson said, « The presence of acid radicals (Cl, F, SO_4), is not necessary for the transport of material through a gaseous phase. Experimental evidence indicates that pure (gaseous) water can carry considerable amounts of non-volatile oxides in solution at pressures not greater than 3000 pounds per square inch and temperatures below 500° C. However, there are no known criteria for distinguishing deposits formed from a gaseous phase from those deposited by a liquid. Such distinctions may be possible by estimating the composition of the solution, estimating the temperature from the mineral assemblage and deciding whether the solution would have been above its critical temperature ».

Discussion was also offered by Zies, Morey, Schaller, Gilluly, and Fleischer.

Shepherd's paper entitled « *Notes on Fluorine* » was presented by E. G. Zies.

C. S. Ross commented, « The granite from Stone Mountain, Georgia, has undergone extreme alteration, probably of a deuteric nature. Abundant tourmaline and sparser radioactive minerals had developed in the granite ».

The paper was discussed by L. C. Graton.

D. J. Cederstrom then said :

« The data presented will probably be of great value to the studies of the fluoride content of various ground waters. Up to the present time no entirely reasonable source for some of these fluorides has been apparent. The paper presented by Dr. Shepherd apparently offers many new possible sources, both in the marine clays and some of the common non-volcanic rocks ».

R. C. Wells remarked as follows :

« As related to the interesting geographic distribution of fluorine in sea bottom samples pointed out by Dr. Shepherd, it may be appropriate to mention that Mr. George Steiger, of the U. S. Geological Survey, by means of spectrographic observations has found a somewhat similar distribution of barium in ocean bottom samples in the Pacific. As I recall it, the highest percentages were found in samples a few hundred miles southwest of the Panama Canal and again more directly west of California ».

Mr. Pedro Sanchez delivered his paper on « *The geographical importance of the Volcanic Axis of Mexico* » in Spanish, with concurrent translation by Mr. Orozco. The paper has been published by the Pan American Institute of Geography and History in 1935.

« This report analyzes the type of mountain which the « Volcanic axis » represents. It presents details on the nature of the relief, the characteristics of the various layers, and the size and location of various parts of the axes.

« The report then mentions and describes the river beds and depressions that are to be found in the vicinity of the axes.

« The report refers to the observations made by Heilprin and recalls the conclusions reached by him. These conclusions are said to be concurred in by various geologists who accept the data presented concerning the age and the nature of the axis.

« The report analyzes the various stages in volcanic activity and the direction of the axis ; that is, east to west.

« The author then proceeds with a detailed study of the orogeny of Mexico. The character and relief of the terrain in several distinct regions are clearly indicated and described. Their developments at various geologic epochs are also sketched. There is given a description of their present aspect, and their relationship with the topography of North America as well as the coastal seas is indicated. The author cites the opinions and conclusions of various foreign and Mexican scientists on the formation, evolution, direction, and configuration, as well as on the origins of the fundamental topographical structure of Mexico. The author points out the relationship existing between the coastal configuration and the direction of mountainous ranges. A study of the marine deposits along the coastal regions and various paleontological data constitute further confirmation. There is evidence of synchronism in strata formation. The forces which operate in the formation of the Earth' s relief are earthquakes and volcanic eruptions. Concluding this part of his report, the author states that in Mexico the tectonic forces have operated in two directions ; northwest- southeast, which is the characteristic trend of North America, and east-west, which corresponds to that of the West Indies.

« The author then proceeds with a study of the relationship between the « Volcanic axis » and earthquakes. He refers to the similar relationship between European earthquakes and the mountain ranges of the Alps, the Carpatians, the Appennines, and the Bohemian Plateau. A study of a seismological map of Mexico will reveal a development parallel to that of Europe.

« The author proceeds then to examine the problem of the « Volcanic axis » from the point of view of geophysics. He refers to certain anomalies in gravity which have been noted (both negative and positive anomalies). He solicits further comparisons and amplifications. The conclusions of MEINESZ on his observations in the Malay Archipelago and the data gathered by the Naval Observatory Expedition made in the Carribean Sea by the submarine S 21 are described. The findings of MEINESZ and the data of the S 21 expedition are analagous to the conclusions arrived at by the author of this report. The essential characteristics of the « Volcanic axis » are then summarized. The author concludes this part of the report with the statement that the « Volcanic axis » constitutes the southern limit of North America. South of the axis Central America begins.

« The author presents a few general considerations on geological theories. Reference is made to the theories of POINCARÉ, serving to reveal the difficulties inherent in any theory seeking to solve the problem of the origin of the Earth. Reference is made also to the theories of LAPLACE and of CHAMBERLIN.

« While various cosmogenic theories seem to satisfy the science of astronomy, the author expresses the opinion that the sciences of physics and chemistry have revealed new difficulties which have cast considerable doubt on previously accepted theories. There is no cosmogenic theory today which is satisfactory to contemporary science. Other difficulties arise as a result of certain geological facts and data. Geologists accept the contraction theory. The author states that the data of geodetic and astronomical observation will not be found in concordance. Various authors, among them HAYFORD and BOWIE, are cited and their contributions in the formulation of the theory of isostasy are duly acknowledged and praised. The author recalls WEGENER' s thories, pointing out that they were soon discarded.

« The only theory which remains at all valid is the theory of isostasy, so admirably defined and presented by William BOWIE. The question still remains as to whether or not this theory explains satisfactorily all aspects of the geological problem.

« The author states that Dutton holds that the volcanic problem is really insoluble and that a critical examination will reveal that the theories cannot stand. The phenomenon of elevation and depression still remains without satisfactory explanation. It is recognized that the theory of isostasy gives some explanation but that it remains incomplete. The author states what he understands isostasy to be. The report concludes as follows: From what has been said, there is no doubt, in view of the present state of science, that the isostatic equilibrium of the Earth is an incontestable fact; that erosion is caused by disequilibrium; and that the manifestations of the recovery of the equilibrium constitute earthquakes and volcanism, represented by plutonic or volcanic rocks ».

Adams asked for information as to the current activity of Mexican volcanoes.

Sanchez replied that volcanic activity was slight at present in Mexico. Only Colima is at all active. In 1918 a series of earthquakes occurred on the axis and the fumaroles of Papocatepetl increased notably at the same time. Professor Ordonez considered the increased fumarolic activity a sign of renewed volcanic activity, but no eruption occurred although the ice caps disappeared due to the fumaroles. During the 1933 earthquakes of Colima the lava within the volcanoes moved up and down, but the fumaroles remained normal. No lava was emitted.

Zies remarked that it is entirely likely that at some future time Colima will become active.

The paper by F. Castaldi, entitled, « *Il cratere di Quarto nei Campi Flegrei* », was read by title.

« L'A. premette, quale Introduzione all'indagine, un cenno storico relativo a quanti si sono occupati, anche se incidentalmente, del cratere in questione. Appartiene ancora alla predetta Introduzione l'elenco e la descrizione delle Carte topografiche e geologiche.

« Nel I capitolo: *I materiali*. L'A. esamina i materiali eruttati dal cratere di Quarto sovrapposti a quelli del II periodo flegreo e specialmente al tufo giallo del Gauro. Egli distingue in: materiali minuti (tufi e ceneri); materiali frammentari (bombe, lapilli, scorie, pomici); materiali massicci (frammenti di lave e lave scoriacee); nell'esame dei materiali l'A. completa la descrizione petrografica con i principali dati chimici e mineralogico.

« Nel II capitolo: *Tettonica*. L'A. premette le indicazioni delle dimensioni del vulcano in questione e l'esame della superficie preesistente al cratere di Quarto, lo attribuisce al I sottoperiodo del terzo periodo eruttivo dei Flegrei e quindi anteriore alla formazione del cratere esterno degli Astroni. L'A. esamina la tettonica della cerchia interna e di quella esterna, specialmente in rapporto all'argine esterno del cratere di Campana e quindi illustra la tettonica di tutto l'apparato.

« Nel III capitolo: *Relazioni con i vulcani limitrofi*. L'A. esamina le relazioni del cratere di Quarto con i preesistenti apparati di tufo giallo e di questi con gli apparati di tufo grigio, ricostruendo i contatti del cratere di Quarto, oltre che con l'apparato di Campana e con gli apparati di Pisano e di questi ultimi con i crateri di Fossa Lupara, in ispecial modo con il cratere di Pianura e di questo con Agnano, con gli Astroni, con la Solfatara, e con il Cigliano.

« Nel IV capitolo: *Morfologia*. L'A. accenna brevemente alla trasformazione subita nel tempo dall' apparato per opera dei fattori exogeni e specialmente dell'acqua piovana, che si deposita abbondante nel fondo e che oggi vien raccolta in appositi canali di scolo e avviata verso il mare per opera della bonifica.

« In fine, nella Conclusione, l'A. accenna sinteticamente all'attività vulcanica nei Flegrei e riprende la questione relativa alle tre fasi o sottoperiodi, così detti dal De Lorenzo, del terzo periodo eruttivo del tufo grigio ».

At 12:15 the meeting was adjourned.

MINUTES OF SEPTEMBER 12, 1939, 15:00 O'CLOCK

Acting Vice-President Zies presided and called upon J. Verhoogen to present the paper by G. Carobbi, « *Ricerche Vesuviane* ». Mr. Verhoogen presented the paper in English translation. It was briefly discussed by Zies, Ross and Verhoogen.

The following papers were read by title: F. Signore, « *L'attività vulcanica nel Golfo di Napoli* »; G. Ponte, « *Rapporto riassuntivo dei fenomeni osservati sull' Etna durante il triennio 1937-1939* ».

Zies presented the following papers by G. Ponte, « *Nuovi metodi per la raccolta dei gas che esalano dalle lave fluenti, dalle rocce arroventate o fuse e dalle fumarole* ». « *Registrazione delle esplosioni vulcaniche per lo studio delle relazioni che esse hanno con le variazioni delle condizioni dell'atmosfera* ». « *Dispositivo per la raccolta dei gas nell' interno dei crateri vulcanici inaccessibili e profondi* ». « *Relazione sulla organizzazione per la difesa contro i danni delle eruzioni dell' Etna* ».

At 16:00 the meeting was adjourned.

MINUTES OF SESSION OF SEPTEMBER 14, 1939

Acting Vice-President Zies called the meeting to order at 10:30.

Present were:

Matuyama, Japan; Arctowski, Poland; and the following from the United States: Goranson, Griggs, Schairer, Gilluly, Ingerson, Wright and Zies.

The following papers were presented by title:

D. Abbruzzese, « *L'attività dello Stromboli dal 1937 al giugno 1939* ».

D. Abbruzzese, « *Colate laviche con pseudocrateri dello Stromboli* ».

G. C. Georgalas, « *Die postvulkanische Fumarolentätigkeit und Wärmehaushalt des Santorin-vulkans* ».

G. Petrucci, « *Sulla possibilità di registrare i movimenti del magma nel condotto eruttivo di un vulcano* ».

A. Lacroix, « *The production of basalt and oceanite in the course of an eruption of the active volcano of the Island of Réunion* ».

A. Lacroix, « *Conclusions drawn from observations made on the recent eruption of the volcano of the Island of Réunion* ».

Zies presented the paper by T. Hidezô «*Volcanoes in the Marianne Islands of the Japanese Mandated South Seas* ».

Schairer expressed his appreciation of this important paper dealing with the little known region.

Discussion was also offered by Matuyama and Zies.

H. Arctowski presented his paper entitled, « *Geothermy* ».

« The temperature gradient in the sub-Carpathian region is much lower than, for example, in Upper Silesia. This may be due to the more recent formation of the Carpathians with a thick root of light and relatively cold rocks. The thermal gradient and certain chemical evidence from the Polish oil fields together suggested that Paleozoic coals should be found to the east of the oil fields. Exploration carried out by the drill in the region of Lvov led to the discovery of anthracite coal. This may be considered the source of the sub-Carpathian oil ».

The author was congratulated on his results by Schairer and Gilluly.

Zies presented the paper by G. Hantke « *Das Vulkangebiet zwischen den Seen Ranco und Puyéhue in Süd-Chile* ».

At 11:50 the meeting adjourned sine die.

At the meeting of the Association of Volcanology, held on September 12, 1939, the following resolution was adopted:

Whereas the phenomena of Hot Springs involve both geological and hydrological questions, and inasmuch as the geological problems are undoubtedly connected with those of volcanism, it seems entirely appropriate and is the sense of this Association that a joint attack be made upon the problem of Hot Springs together with the Association of Hydrology. The question for discussion at the next Assembly of the International Union might be, « Geology, Geochemistry and Hydrology of Thermal Springs ».

JAMES GILLULY
Acting General Secretary
International Association
of Volcanology

LEASON H. ADAMS
Acting President
International Association
of Volcanology

The second, and final, plenary session.

Resolutions adopted by the General Assembly.

I. *International Isostatic Bureau at Helsinki.*

The International Union of Geodesy and Geophysics expresses its high appreciation of the scientific work already done by the International Isostatic Institute at Helsinki under the leadership of Dr. W. Heiskanen and expresses the opinion that the continuation of this Bureau is of the greatest importance for all the sciences engaged in the study of the Earth's crust.

II. *Recommendation for more Gravity Determinations.*

The International Union of Geodesy and Geophysics wishes to express anew that it is of the highest importance not only for the Geophysical research but also for the determination of the geoid, that gravity work should be extended, especially, in regions where no such work has been done.

III. *Recommendations for Determining the Geoid by Astronomical Observations.*

The International Association of Geodesy, recognising the importance of the method of determining the form of the Geoid by integration of values of the deviation of the vertical, either along lines, or over networks, expresses the hope that all countries will carry out such work in the way best suited to their special circumstances. The work of this nature mentioned in the « Rapport sur les deviations de la verticale » to the Washington meeting, provides examples of valuable progress in the field, particulary in India and Switzerland.

IV. *Recommendation for Torsion Balance Observations.*

The International Union of Geodesy and Geophysics wishes to recommend that, in addition to other observations for determining the geoid, also observations with the torsion balance should be made at suitable stations for this purpose.

V. *Recommendation for more Observations of Earth-tides.*

The International Union of Geodesy and Geophysics deems that the establishment of further stations provided with Trifilar-Gravimeters and horizontal double pendulums and at different distances from the coast to be necessary for the study of elastic Earth-tides and for the variations in the elasticity of the rocks forming the earth's crust.

VI. *Recommendation for the Extended Use of the Photographic Zenith Tube.*

The International Association of Geodesy expresses the opinion that it would be of great importance to geodesy and geophysics to extend the use of the photographic zenith tube to a number of stations throughout the world.

VII. *The Use of Non-magnetic ships.*

The International Union of Geodesy and Geophysics strongly recommends the governments interested in the magnetic survey of the oceans make provision for the building of non-magnetic vessels to continue accurate geomagnetic determinations at sea.

VIII. *Recommending the Use of Networks of Synoptic Radio-sonde Stations.*

The International Union of Geodesy and Geophysics has been impressed by the new possibilities for theoretical and practical meteorology opened by the radio-sonde ascents, and desire to express its whole-hearted support of the resolution passed by the « Organisation Météorologique Internationale » in Salzburg in 1937 concerning the desirability of the establishment of networks of synoptic radiosonde stations.

IX. *Recommending the Charting of the Suboceanic Crust.*

Whereas an accurate knowledge of the configuration of the surface of the earth under water areas is essential to all phases of Earth Science, the International Union of Geodesy and Geophysic calls attention to the desirability of a comprehensive programme for the proper charting of the suboceanic crust so as to show its true configuration.

X. *Recommending the study of Rocks at High Pressures and Temperature.*

The International Union of Geodesy and Geophysics stresses the need for accurate information regarding the behaviour of rocks at high pressure and temperatures. The production of such information requires firstly extended, carefully planned, and well directed experimentation in the laboratory over a period of years; secondly an extensive programme of the collection of field evidence; and thirdly the computation and correlation of such field and laboratory results. The International Union of Geodesy and Geophysics, in urging continued study of the deformational properties of rock materials, will give all possible encouragement and assistance toward the development and continuance of research programmes such as can make significant contributions to this vital field of Earth Science.

XI. *Acknowledging the progress of Seismological Work at Sea.*

The International Union of Geodesy and Geophysics notes with satisfaction the progress of Seismological work at sea and the part taken in this work by the British Navy, by the Coast and Geodetic Survey, and by the Woods Hole Oceanographic Institute of the United States.

XII. *The American Institute of Geography and History.*

The International Union of Geodesy and Geophysics expresses its high appreciation of the activities of the Pan American Institute of Geography and History for the coordination and encouragement of scientific investigations in the different States of the American Continents and tenders a cordial invitation to this Institute to cooperate for furthering the common scientific interests and, if possible, to send representatives to the Assemblies of the Union.

XIII. *New Seismological Stations.*

The International Union of Geodesy and Geophysics learns with great satisfaction of the establishment of new seismological stations in several regions in which there had been previously no efficient seismographs. Congratulations and thanks are offered the authorities responsible for providing these stations, viz: Bermuda, Fiji, Pameete, Martinique, Montserrat, Brisbane, and Johannesburg.

XIV. *Canadian Seismological Stations.*

The International Union of Geodesy and Geophysics notes with satisfaction the continuation of the seismological stations at Toronto and Victoria by the Government of the Dominion of Canada. The geographic position of Victoria and its long history make it essential that this station should not lapse. If at some future time stations for geophysical investigations should be established in central and northern Canada it would be highly desirable to include seismographs in the equipment.

XV. *Proposed Seismological Station at Tristan da Cunha.*

The International Union of Geodesy and Geophysics having learned that the establishment of a meteorological station in Tristan da Cunha by the government of South Africa is under consideration, asks the Government to include seismographs in the equipment of the station. Seismological observations at such a station would be of great value in the location of earthquakes in the southern hemisphere and in the study of the structure of the bed of the Atlantic Ocean.

XVI. *Seismological Stations in the Pacific Ocean Area.*

The International Union of Geodesy and Geophysics endorses the views expressed in resolutions of the Pan Pacific Science Congress, meeting in San Francisco in August, 1939, relative to the need for establishing additional seismological stations in the Pacific Ocean Area viz:....

XVII. *Recommending the Record and Storage of Geodetic and Geophysical Work carried out by Petroleum and Mining Companies.*

It is the opinion of the International Union of Geodesy and Geophysics that an agency should be designated and created in each member country where geodetic and geophysical work is done by petroleum and mining companies to secure from these companies geodetic and geophysical data which may no longer be of commercial and economic value to them. Those data would be of great scientific importance. It is hoped that National Committees will make efforts to secure and use the data referred to.

A. MICHEL-LÉVY

Emploi des explosifs pour la synthèse par pneumatolyse des minéraux des roches de profondeur (granite). Métamorphisme artificiel.

Discours du Président de l'Association de Volcanologie
à la Septième Assemblée générale à Washington,
6-15 Septembre 1939.

(Avec 13 planches)

Le Comité américain d' organisation de la VII^e Assemblée de l' Union internationale de Géodésie et de Géophysique a demandé au Président de chacune des Associations qui la composent de prendre la parole devant des représentants des diverses Associations soeurs. C' est là une heureuse innovation qui pourra susciter de communs efforts pour de nouvelles recherches.

Au début de cette allocution, mon premier devoir est d' exprimer la haute satisfaction que nous éprouvons de cette réunion à Washington, capitale d' un puissant pays qui par tant d' éminents savants et de citoyens généreux a si largement contribué à l'avancement de la science. Ai-je besoin de rappeler le rôle considérable joué dans la pétrographie, en particulier, par les travaux sur la chimie des roches que l' on doit à W. Cross, Iddings, Pearson et Washington et le magnifique ensemble de recherches poursuivies au Laboratoire de Géophysique de Washington sur la synthèse des minéraux et la connaissance de leurs diagrammes d' équilibre.

L'Association de Volcanologie a, depuis l'Assemblée d' Edimbourg, publié 5 Tomes de son Bulletin qui apportent la preuve de son activité scientifique. D' importants travaux émanant de volcanologues anglais, français, grecs, hollandais, italiens, japonais, portugais, suisses, etc. y ont été publiés ; ces travaux concernent le volcanisme actif aussi bien que le volcanisme éteint, les roches effusives et les roches de profondeur.

Je tiens à remercier publiquement notre Secrétaire général, le Professeur Francesco SIGNORE, du concours dévoué qu'il n'a cessé d'apporter à notre Association pour assurer d'actives relations entre ses membres et veiller aussi parfaitement que possible à la publication de son Bulletin.

Un autre fait qui me paraît devoir être signalé, est l'aide financière que le Bureau a pu apporter à quelques savants pour des recherches intéressant la volcanologie, ceci, sur la demande des Comités nationaux et en appoint à des missions d'Etat. Il s'est conformé en cela aux voeux formulés à l'Assemblée d'Edimbourg. Il est souhaitable que ce ne soit là qu'un commencement et que l'Association puisse, dans l'avenir, apporter son concours à de nouveaux travaux de volcanologie autrement que par la seule publication de son Bulletin.

Je ne veux pas me contenter de ne parler ici que de généralités et je vais vous exposer quelques résultats de mes récentes recherches.

⁂

Ces recherches sont relatives à la reproduction artificielle de minéraux par pneumatolyse sous pression de gaz et de vapeur d'eau et au métamorphisme artificiel des roches, à l'aide d'explosifs. Elles intéressent dans une certaine mesure le volcanisme de surface mais surtout les phénomènes éruptifs qui se passent dans les profondeurs.

Depuis l'époque lointaine où j'étais préparateur au Collège de France, je suis resté préoccupé du problème de la reproduction artificielle du granite devant lequel s'étaient arrêtés FOUQUÉ et Auguste MICHEL-LÉVY dans leurs essais de synthèse des roches, faute de pouvoir réaliser de hautes pressions.

Amené il y a douze ans par les hasards de la recherche scientifique à entrer en relations avec un officier supérieur du Service français des Poudres, l'Ingénieur général H. Muraour, j'ai entrepris une série d'observations de poudres de guerre et d'explosif, au microscope polarisant ou sur des bancs d'optique photographiques, qui nous ont conduit à l'établissement d'une technique nouvelle basée sur l'emploi de très petites quantités d'explosifs ; nous l'avons dénommée « *micropyrotechnie* ».

C'est par une application de la micropyrotechnie, génératrice de hautes températures et de hautes pressions, que j'ai été conduit aux essais dont je vais parler.

Propriétés des explosifs brisants

Une petite quantité d'un explosif très brisant placé dans une rainure circulaire d'un bloc cylindrique de laiton (0^{cm^3}, 4 d'un mélange de tétranitrométhane et de toluène à combustion complète, explosif liquide, ou environ 1 gramme d'hexogène, explosif solide, en poudre finement cristallisée), amorcé en un point du cercle par une petite charge d'un explosif sensible (perchlorate de diazo de métanitraniline), fournit au point opposé à l'amorçage une puissante luminosité en forme de colonne lumineuse verticale, qui correspond à la rencontre de trains d'ondes de choc dont la vitesse de translation au départ atteint 6.000 à 8.000 m. s. Cette rencontre détermine des pressions très considérables, génératrices de très hautes températures. Non seulement la rencontre entre elles-mêmes des ondes de choc, mais le heurt par elles d'un obstacle quelconque détermine une puissante luminosité ; même un obstacle aussi léger qu'une mince feuille de papier suffit à produire cette luminosité, tant est grande son inertie eu égard à la vitesse des ondes de choc.

Les effets de ces ondes de choc sont indépendants de ceux des gaz issus de la détonation et ils leurs sont antérieurs. C'est ce que montre l'observation de blocs cylindriques de plomb où l'on a fait détonner l'explosif. Dans ce cas, les effets des ondes de choc déterminent sur les parois verticales du bloc l'arrachement de pelures métalliques, alors que les gaz transforment la rainure en une large cuvette circulaire ; l' étude quasi-cinématographique de la détonation à l'aide de photographies faites de 100 en 100 millièmes de seconde montre que le phénomène lumineux majeur se produit au début de la formation de ces pelures et que l' effet des gaz qui agrandissent la rainure est postérieur.

Je rappellerai, entre parenthèses, que c' est par un phénomène d' onde de choc qu' ont été détruites les maisons de la Ville de St-Pierre de la Martinique, lors de l' éruption de la Montagne Pelée du 8 Mai 1902. Les apports de cendres brûlantes ne sont venus qu' à la suite de cette destruction.

Nous avons montré que l' intensité du phénomène lumineux varie considérablement suivant le milieu gazeux dans lequel se propagent les ondes de choc ; très faible dans l' acide carbonique, elle est très considérable dans l'argon. Elle est d'autant plus élevée que la chaleur spécifique du gaz entourant est plus faible ; et à chaleur spécifique égale, elle est d'autant plus grande que la densité du gaz est plus forte.

Dans l' argon, l' intensité lumineuse semble pouvoir atteindre approximativement 14 millions de bougies pour une surface émettrice inférieure à 2^{cm^2} ; c' est une source lumineuse d' intensité supérieure à celle du soleil.

La photographie par réflexion de disques tournant a 10.000 tours minute ou directe, sur film enroulés sur tambour tournant à 90 m. s., a permis de préciser la durée de l' éclat lumineux ; elle est d' environ 3 millioniémes de seconde.

L' étude des spectres de telles luminosités dans l' argon, qui sont à fonds continu et vont très loin dans l' ultra-violet, prouve que les températures atteintes dans les rencontres d' ondes de choc s' élèvent considérablement ; elles semblent pouvoir atteindre 35.000 degrés. Les spectres de raies de métaux mis en suspension dans l' argon sous forme gazeuse et exposés à l' onde de choc rappellent ceux du fil éclaté d'Anderson ou de l' étincelle sous l' eau et correspondent à un très haut degré d'excitation de la matière.

Synthèse de minéraux

On comprendra que devant les propriétés de ces explosifs fournissant dans l'onde de choc de hautes pressions instantanées estimées être de l'ordre de 50 tonnes et de très hautes températures, comme on vient de le voir, j'ai songé à les utiliser pour la synthèse de minéraux. Dans de premiers essais exécutés au sein de bombes d'acier de grande capacité (environ 700^{cm^3}), j'ai fait détoner des mélanges intimes d'explosifs et de produits minéraux en poudres fines (minéraux, verres de minéraux, mélanges chimiques), placés dans la rainure circulaire des blocs cylindriques de laiton dont j'ai parlé précédemment. L'introduction dans les explosifs de faibles quantités de ces produits (moins de ¼ en poids) ne diminue pas sensiblement les effets lumineux et, en conséquence, les températures dans l'onde de choc. Après détonation, on remarque à l'ouverture de la bombe le départ d'un nuage léger de matière impondérable qui monte dans l'atmosphère ; sur les parois froides de la bombe, on recueille, au pinceau une poussière très fine qui s'est montrée, au microscope, faite de fines sphérules de verre bulleux, de dimensions variées, allant d'une fraction de micron à quelques microns. Ainsi, la détonation du mélange d'explosif brisant et de matière minérale produit une atmosphère gazeuse, mélange des gaz de l'explosion et de produits minéraux devenus gazeux, comparable à une atmosphère de nébuleuse ; par une détente trop brusque et au contact d'une paroi froide, il ne se produit que des verres ponceux.

J'ai alors supposé qu'en faisant détoner le mélange explosif dans une enceinte restreinte et étanche, où se conserveraient de hautes pressions et en recuisant pendant un temps suffisant à des températures voisines de 500°, on obtiendrait non plus des verres, mais des matières cristallisées. Cette hypothèse s'est pleinement vérifiée.

Dans une bombe d' acier cylindrique de 80 mm. de diamètre et de 150 mm. de hauteur est réservé au centre un trou où sont engagés des tubes, fermés à un bout, de laiton ou de cuivre, de nickel, d' aluminium ou d' argent, emboîtés à deux, l' un dans l'autre, en les opposant, assurant l' étanchéité jusqu' à des temperatures d' environ 650°. Le volume de la chambre intérieure est de 3 à 4^{cm^3}. La charge d' hexogène est de $1^{gr}50$; la quantité de matières minérales est de $0^{gr}25$. Le vide est fait dans cette chambre, puis de l'argon y est introduit. La bombe chargée et fermée est placée dans un four électrique préalablement chauffé. L'élévation de température au coeur de la bombe détermine la détonation après 5 minutes vers 150°. La pression calculée est, après la détonation, de 3.000 à 4.000 kg. par cm^2, à 500°. La bombe a été maintenue dans le four pendant 4 à 12 jours ; sortie du four, après refroidissement, elle est percée à sa base d' un trou très fin pour permettre la détente lente des gaz. L' ouverture est faite ensuite par sciage et dégagement au tour des tubes intérieurs.

La composition des gaz de la détonation est la suivante : azote 33,3 %, oxyde de carbone 25 %, eau 25 %, acide carbonique 8,3 %, hydrogène 8,3 % ; en outre un peu de chlore est apporté par les quelques milligrammes de l' explosif d'amorçage.

Dans une première série d' essais, il a été procédé *sans* addition d' eau et d'alcalis.

Les minéraux obtenus ont été, en partant de silice mélangée à l' explosif, avec une chambre en laiton dont les parois ont libéré du zinc, la *zincite*, la *willémite*, la *smithsonite*, oxyde, silicate, carbonate de zinc.

En partant de poudre de fonte mélangée à l' explosif, dans un tube d' acier, on a obtenu de la *magnétite* bien cristallisée et un résidu graphiteux.

En partant d' alumine mélangée à l' explosif dans un tube d'aluminium, on a obtenu le *nitrure d'aluminium* et un carbonate d'aluminium.

En partant de nickel mélangé à l' explosif dans un tube de nickel, on a obtenu le *nickel magnétiqne* (Ni^3O^4).

En partant d' un mélange de silice, alumine, et carbonate de potasse ou de soude dans l' explosif, on a obtenu l' *orthose* et l' *albite* à l' état de fibres, associées en sphérolites, formant de véritables pyromérides.

Enfin en partant d' un mélange, de silice, alumine et carbonate de calcium, dans l' explosif, il s' est fait de l'*anorthite*, en sphérolites et en rosettes de cristaux libres, mâclés suivant la loi de l'albite, avec un accompagnement de calcite.

Les dimensions des minéraux formés librement, par pneumatolyse, varient entre quelques microns et 15 dixièmes de m.m. Ils se présentent en croûtes, en glomérules ou en rosettes, en feutrages, sur les parois de la chambre de détonation, mêlés de perles métalliques ; on peut y déceler un ordre de cristallisation.

J' ai dû recourir pour leur détermination, à la fois aux méthodes optiques au microscope polarisant, à la microchimie et, avec la précieuse collaboration de J. Wyart, à l' emploi des rayons X.

Dans une deuxième série d' essais, provoquée par l' impossibilité d' obtenir le quartz avec les seuls gaz de la détonation, nous avons fait intervenir l' action d' une eau surajoutée. Un tube supplémentaire, très mince, formant nacelle et contenant l' explosif et les produits minéraux, est placé à la partie supérieure de la chambre intérieure de la bombe. L' eau est mise dans la partie inférieure de cette chambre. Au moment de la détonation le tube supplémentaire se rompt. La vapeur d' eau et les gaz de la détonation se mélangent.

Avec une silice provenant de quartz fondu nous avons ainsi obtenu après un recuit de 6 jours à 550° dans une chambre de cuivre ou d' argent une ponce vitreuse légère contenant de fines aiguilles cristallines ; aux rayons X le diagramme de poudre donné par cette ponce est un beau diagramme de *cristobalite*.

En ajoutant de la potasse ou de la soude caustique à l'eau distillée c'est le *quartz* α bien cristallisé qui est né, formant des prismes pyramidés groupés en glomérules accolés les uns aux autres, avec un accompagnement de prismes bipyramidés mieux nourris que les autres.

Afin de définir la part d'influence des effets de la pression et de l'échauffement instantanés dans l'onde de choc, et celle du recuit prolongé sous la pression des gaz de la détonation, des essais ont été faits en mettant les produits minéraux non plus dans l'explosif, mais dans l'eau, en bas du tube intérieur ; l'explosif ne servant plus désormais qu'à créer la pression de 3 à 4.000 kg pendant le recuit à 500°. La silice dans l'eau seule ou additionnée de 1 °/₀₀ de potasse, a donné la cristobalite ; dans l'eau à ½ % de potasse, elle a donné le quartz, ce quartz étant moins parfaitement cristallisé que dans le cas précédent ; par contre, les bombes avec matières dans l'explosif, sorties du four et refroidies de suite après la détonation, en supprimant le recuit, n'ont donné que des verres. Il semble que le mélange avec l'explosif ne fait que diviser la matière probablement jusqu'à l'atome, facilitant ainsi de promptes recristallisations. Le recuit sous pression est nécessaire pour que ces dernières aient lieu.

De ce premier ensemble d'essais, je crois que l'on peut déduire quelques conclusions. C'est d'abord l'évidence de la genèse possible dans les profondeurs de minéraux des roches par pneumatolyse, avec passage directe de l'état gazeux à l'état solide. C'est ensuite qu'à des températures non très élevées, voisines de 500°, et à des pressions de l'ordre de 3.000 à 4.000 kg par cm^2, les principaux minéraux du granite, le quartz et les feldspaths, peuvent prendre naissance, avec cette observation que le quartz semble exiger la présence d'eau en abondance à l'état de vapeur ou de gaz, accompagnée d'un alcali ; ce dernier point trouve son contrôle dans la nature ; il n'existe pas en effet de roche éruptive de profondeur faite uniquement de quartz ; les feldspaths alcalins accompagnent toujours ce dernier dans les granites, les aplites et les pegmatites. Dans les essais sur le quartz, nous avons retrouvé l' apparition d' inclusions liquides à libelle mobile, si fréquentes pour ne pas dire constantes au sein des quartz des granites et des gneiss. Nous voyons là une similitude de résultats tendant à prouver une similitude de conditions de genèse au point de vue températures et pressions. Il est d'ailleurs à remarquer qu' avec des densités de roches qui, compte tenu de la composition chimique et de la compressibilité, doivent aller de 2,5 à 4, et avec un degré géothermique qui peut varier de 1° par 15 mètres d' enfoncement à 1° par 30 mètres, les profondeurs comprises entre 10.000 et 20.000 mètres réalisent des températures et des pressions auxquelles approchent celles de nos expériences. C' est à ces profondeurs que paraissent susceptibles de naître les granites.

Métamorphisme artificiel des roches

De tels résultats nous ont incités tout récemment à soumettre de petits morceaux de roches à des recuits sous pression, avec accompagnement d' eau seule ou d' eau et d'alcalis, dans les bombes, pour y tenter de réaliser un métamorphisme artificiel. Les roches soumises jusqu' à ce jour à ces essais ont été un chloritoschiste assez largement cristallin, un schiste calcarifère fin, une argile, un conglomérat à petits galets de quartz, de microcline, avec débris de micas, dans un ciment calcaire.

Après des recuits de 12 jours à 600°, ces roches, observées en plaques minces, ont montré d' abondantes néogénèses cristallines, nées « in situ ». Dans le chloritoschiste formé principalement de clinochlore et de grains d' oligiste, il s' est fait du mica blanc, des spinelles, un minéral à réfringence et à biréfringence élevées, rappelant l' épidote ; ces transformations ont eu lieu à la limite de l' oligiste et du clinochlore et dans les plans de clivage de ce dernier.

Dans le schiste fin, les agglomérats de calcite ont été partiellement transformés en un minéral rappelant l' augite ; en outre à la surface de l' échantillon, il s' était fait un enduit de fines aiguilles s' éteignant obliquement et qui, aux rayons X, ont donné un diagramme d'anorthite.

L' argile plastique primitivement riche en halloysite, s'est transformée en une argile cassante riche en séricite, avec taches de cristaux de calcite et, en surface, croûtes de fins cristaux d'augite agyrinique probable.

Le conglomérat à ciment calcaire a été retrouvé couvert d' un feutrage épais de fins cristaux, pénétrant en profondeur dans des géodes. En plaque mince, il se montre transformé par place en une véritable épidotite.

Le processus de métamorphisme résulte ici nettement de la pénétration des gaz sous haute pression qui, dans le cas des roches holocristallines, cheminent par tous les joints des minéraux entre eux et par les plans de clivage ; les nouvelles cristallisations partent de ces joints et gagnent progressivement au sein des cristaux primitifs. Dans le cas de roches à éléments fins, entourés de matières colloïdales, ces gaz se propagent partout dans la roche en imbibant ces dernières. Les néogenèses cristallines apparaissent un peu partout sans que l' on puisse distinguer de lieux de cheminement.

Dans les deux cas, les roches soumises aux essais se sont montrées entièrement pénétrables aux gaz sous haute pression ; l'action de l' eau seule est manifeste mais encore faible pendant la durée relativement brève de ces expériences ; celle de l' eau accompagnée d' alcalis a été bien plus intense.

Conclusions

Je crois que ces expériences de genèse de minéraux par pneumatolyse sous hautes pressions et de métamorphisme artificiel apportent une confirmation certaine aux théories qui ont attribué le métamorphisme de contact des roches et le métamorphisme régional principalement à des pénétrations de gaz et de vapeurs d' eau s' ajoutant à l' élévation de température. Les néogénèses « *lit par lit* » et celles « *par superposition* » distinguées autrefois dans le métamophisme de contact peuvent se comparer aux néogénèses constatées dans les joints du chloritoschiste étudié ci-dessus et à celles formées en tous les points de l'argile. La remise en oeuvre sur place des éléments des minéraux préexistants au coeur des roches, avec apport ou non d' éléments nouveaux, en milieu ne passant pas par un état liquide généralisé, apparaît, en tous cas, certaine.

Ainsi la micropyrotechnie a permis de réaliser des synthèses de minéraux et un métamorphisme des roches dans des conditions de pression et de température qui se rapprochent de celles dans lesquelles doit se former le granite. Je la crois susceptible d'ajouter des données nouvelles à celles, déjà si remarquables, accumulées antérieurement, en particulier par les savants physiciens du Laboratoire de Géophysique de Washington et par van NIEUWENBURG.

Translation of presidential address.

A. MICHEL-LÉVY

Use of explosives for the synthesis by pneumatolysis of the minerals of deepseated rocks (Granite). Artificial metamorphism.

(With 13 plates)

The American Organizing Committee of the Seventh Assembly of the International Union of Geodesy and Geophysics has asked the president of each of the Association which compose it to speak before the representatives of the various sister Associations. This is a happy innovation which may well arouse common efforts for new research work.

At the beginning of this address my first duty is to express the great satisfaction we feel about this meeting at Washington, capital of a mighty country which has so largely contributed to the advancement of science through so many eminent scholars and generous citizens. Need I recall the considerable role played in petrology, in particular, by the work on the chemistry of rocks which we owe to W. CROSS, IDDINGS, PEARSON and WASHINGTON, and the magnificent group of investigations carried on at the Geophysical Laboratory of Washington on the synthesis of minerals and their equilibrium diagrams ?

Since the Edinburgh Assembly the Association of Volcanology has published five volumes of its Bulletin which furnish the proof of its scientific activity. Important studies emanating from English, French, Greek, Dutch, Italian, Japanese, Portuguese, Swiss and other volcanologists have been published in the Bulletin ; these studies deal with active as well as extinct volcanic action, effusive rocks and intrusive rocks.

I wish publicly to thank our General Secretary, Prof. Francesco SIGNORE, for the devoted cooperation which he has unfailingly given our Association for the purpose of assuring active relations among its members, and of taking care as perfectly as possible of the publication of its Bulletin.

Another fact which seems to me worthy of mention is the financial aid that the Bureau has been able to afford some scholars for studies concerning volcanology, at the request of national committees and supplementing state missions. In this matter it has acted in conformity with the wishes expressed at the Edinburgh Assembly. It is to be desired that this may be only a beginning, and that in the future the Association may be able to extend its cooperation to new studies on volcanology in other ways than by the mere publication of its Bulletin.

I do not want to be satisfied with speaking here of generalities alone and I am going to tell you about some results of my recent research work.

⁂

These studies relate to the artificial production of minerals by pneumatolysis under the pressure of gas and of steam, and to the artificial metamorphism of rocks by the aid of explosives. They concern in a certain measure surface volcanic action but especially the eruptive phenomena which have their origin in the depths.

Since the distant epoch when I was a student at the College of France, I have always been interested in the problem of the artificial reproduction of granite before which FOUQUÉ and Auguste MICHEL-LÉVY were halted in their attempt at synthesis of rocks, because of inability to realize high pressures.

Led some twelve years ago by the fortuitous events of scientific research to enter into relations with a higher officer of the French Powder Service, Engineer-General H. Muraour, I undertook a series of observations of military powders and explosives, under the polarizing microscope or on photographic optical banks, which brought us to the development of a new technique based upon the use of very small quantities of explosives; we have named it « *micropyrotechnics* » (detonating technique).

It was by an application of micropyrotechnics, which generate high temperatures and high pressures, that I was led to the experiments of which I am going to speak.

Properties of detonating explosives

A small quantity of a detonating explosive placed in a circular groove of a cylindrical block of bronze (0.4 cubic centimeters of a mixture of tetranitromethane and of toluene having complete combustion as a liquid explosive, or about 1 gramme of hexogene in finely crystallized powder as a solid explosive) primed at a point of the circle by a small charge of a sensitive explosive (perchlorate of diazo metanitraniline), furnishes at the point opposite to the priming a powerful luminosity in the form of a vertical luminous column, which corresponds to the impact of trains of shock waves of which the velocity of translation at the outset attains 6,000 to 8,000 meters per second. This impact causes very considerable pressures which generate very high temperatures. Not only the interference between themselves of the shock waves (see Figure 1), but also their collision against some obstacle causes a strong luminosity ; even an obstacle so light in weight as a thin sheet of paper suffices to produce this luminosity, so great is its inertia with respect to the velocities of the shock waves. (See Figure 2).

The effects of these shock waves are independent of those of the gases given off by the detonation and they precede them. This is what is shown by observation of cylindrical blocks of lead on which the explosive is set off. In this case, the effects of the shock waves cause the tearing away of metallic scales from the vertical walls of the block, while the gases transform the groove into a large circular basin; the quasi-cinematographic examination of the detonation by means of photographs taken at each 100 thousandths of a second shows that the major luminous phenomenon is produced at the beginning of the formation of these scales, and that the effect of the gases which enlarge the groove is subsequent.

I shall recall, parenthetically, that it was by a phenomenon of shock wave that the houses of the city of St. Pierre in Martinique were destroyed at the time of the eruption of Mont Pelée on May 8, 1902. The deposition of burning cinders came only after this destruction.

We have shown that the intensity of the luminous phenomenon varies considerably according to the gaseous medium in which the shock waves are propagated; it is very weak in carbonic acid but very considerable in argon. It varies inversely as the specific heat of the (see Figures 3 and 4) surrounding gas; and at equal specific heat, it is greater as the density of the gas is greater.

In argon the luminous intensity seems able to attain approximately 14 million candle power for a surface of emission less than 2 square centimeters; this is a luminous source of intensity higher than that of the Sun.

Photography by reflection of discs turning at 10.000 r. p. m. or direct photography, on film rolled on a drum turning at 90 meters per second, permitted the fixing of the duration of the luminous flash; it is about 3 millionths of a second.

The examination of the spectra of such luminosities in argon, which are continuous and go very far into the ultra-violet, proves that the temperatures attained in the impacts of shock waves rise considerably; they appear able to reach 35.000 degrees C. The spectra of the particles of metal placed in suspension in the argon in gaseous form and exposed to the shock wave recall those of the exploded wires of Anderson or of the spark under water, and correspond to a very high degree of excitation of matter.

Synthesis of minerals

It will be understood that in view of the properties of these explosives, furnishing in the shock waves high instantaneous pressures estimated as being on the order of 50 tons and very high temperatures, as has just been seen, I conceived the idea of using them for the synthesis of minerals. In the first experiments executed inside of steel bombs of large capacity (about 700 cubic centimeters), I set off intimate mixtures of explosives and mineral products in fine powders (minerals, mineral glasses, chemical mixtures), placed in the circular groove of the cylindrical blocks of bronze of which I spoke above. The introduction into the explosives of small quantities of these products (less than $^1/_4$ by weight) does not sensibly diminish the luminous effects, and, consequently, the temperatures in the shock wave. After detonation, upon opening the bomb there was noticed the escape of a light cloud of imponderable matter which rose in the atmosphere; on the cold walls of the bomb, a brush was used to collect a very fine dust which showed itself under the microscope to be made of fine spherules of vesicular glass, of varied dimensions, ranging from a fraction of a micron to several microns. In this manner the setting off of the mixture of detonating explosive and of mineral matter produces a gaseous atmosphere, which is a mixture of the gases of explosion and of mineral products become gaseous, comparable to a nebulous atmosphere; by a too abrupt relaxation and upon contact with a cold surface, only reddish glasses are produced.

Thereupon I supposed that by setting off the explosive mixture in a restricted and airtight inclosure, where the high pressures would be preserved, and by reheating during a sufficient time at temperatures near 500° C, glass would no longer be obtained, but crystallized matters. This hypothesis was fully confirmed.

In a cylindrical steel bomb 80 mm in diameter and 150 mm in height, a hole is kept at the center into which are introduced tubes, closed at one end, of bronze or of copper, of nickel, of aluminium or silver, so nested as to assure airtightness up to temperatures of about 650° C. The volume of the inside chamber is from 3 to 4 cubic centimeters. The charge of hexogene is 1.50 grams; the quantity of mineral matters is 0.25 gram. A vacuum is produced in this chamber and the argon is then introduced. The charged and closed bomb is placed in an electric oven previously heated. The raising of the temperature at the heart of the bomb causes the detonation after 5 minutes at about 150°. After the detonation the calculated pressure is from 3.000 to 4.000 kg per square centimeter, at 500° C. The bomb was kept in the oven for 4 to 12 days; taken from the oven, it was pierced after cooling by a very fine hole at its base to allow the slow escape of the gases. Opening was then effected by sawing and clearing away from around the inside tubes.

The composition of the gases of detonation was as follows :

Nitrogen	33.3 per cent
Oxide of carbon	25.0 per cent
Water	25.0 per cent
Carbonic acid	8.3 per cent
Hydrogen	8.3 per cent

plus a little chlorine due to the few milligrams of the priming explosive.

In a first series of experiments, no water or alkalis were used.

Starting with silica mixed with the explosive, and with a chamber of bronze the walls of which gave off zinc, the minerals obtained were *zincite*, *willemite*, *smithsonite*, oxide, silicate and carbonate of zinc.

Starting with soldering powder mixed with the explosive, in a steel tube, well crystallized *magnetite* and a graphitic residue resulted.

Starting with alumina mixed with the explosive in a tube of aluminium, *nitride of aluminium* and a carbonate of aluminium were obtained.

Starting with nickel mixed with the explosive in a nickel tube, *magnetic nickel* (Ni_3O_4) was obtained.

Starting with a mixture of silica, alumina, and carbonate of potash or of soda in the explosive, there was obtained feldspar *(orthose)* and *albite* in a fibrous state, associated in spherolites, forming real pyromerides. (See Figures 5 and 6).

Finally, starting with a mixture of silica, alumina and carbonate of calcium in the explosive, there resulted *anorthite* in spherolites and in rosettes of free crystals, oriented according to the law of albite, with an accompaniment of calcite. (See Figures 7 and 8).

The dimensions of the minerals formed freely by pneumatolysis vary between a few microns and 15 tenths mm. They appear in crusts, in glomerules or in rosettes, in feltings, on the walls of the detonation chamber, mixed with metallic pearls; an order of crystallization can be discerned.

For their determination I had to have recourse both to optical methods with polarizing microscope, to microchemistry and, with the valuable collaboration of J. WYART, to the use of X rays.

In a second series of experiments, called for by the impossibility of obtaining quartz with only the gases of detonation, we introduced the action of additional water. A supplementary very thin tube, suspended within the bomb and containing the explosive and mineral products, is placed in the upper part of the inside chamber of the bomb. The water is placed in the lower part of this chamber. At the moment of detonation the supplementary tube is broken. The steam and gases of detonation are mingled.

With a silica resulting from fused quartz we thus obtained, after reheating for 6 days at 550° C in a chamber of copper or of silver, a light vitreous pumice containing fine crystalline needles; with X rays the diagram of the powder supplied by this pumice is a fine diagram of *cristobalite.*

Adding potash or caustic soda to distilled water well crystallized α quartz is produced, forming pyramided prisms grouped in glomerules coupled to each other, with an accompaniment of bipyramided prisms better developed than the others. (See Figures 9 and 10).

In order to fix the share of influence of the effects of instantaneous pressure and heating in the shock wave, and that of the prolonged reheating under the pressure of the gases of detonation, experiments were made in no longer placing the mineral products in the explosive but in the water, at the bottom of the inside tube, the explosives no longer serving except to create the pressure of 3.000 to 4.000 kg during the reheating at 500° C. Silica in water alone or with the addition of 1 ‰ of potash gave crystobalite; in water with ½ per cent of potash, it gave quartz, this quartz being less perfectly crystallized than in the preceding case; on the other hand, the bombs with the matters in the explosives, but removed from the oven and cooled right after the detonation without reheating, produced only glass. It appears that the mixing with the explosive does nothing more than divide the material, probably as far as the atom, thus facilitating prompt recrystallizations. The reheating under pressure is necessary in order that the latter may take place.

From this first group of experiments, I believe that several conclusions may be drawn. There is first the evidence of the possible genesis in the depths of rock minerals by pneumatolysis, with direct passage from the gaseous to the solid state. There is then evidence that at temperatures not very high, near 500° C, and at pressures of the order of 3.000 to 4.000 kg per square centimeter, the principal minerals of granite, quartz and the feldspars, may begin to develop, with this condition that quartz seems to require the presence of water in abundance in the state of steam or gas, accompanied by an alkali; this latter point has its confirmation in nature; there does not in fact exist eruptive rock coming from considerable depth composed solely of quartz; alkaline feldspars always accompany the latter in granites, the aplites and pegmatites. In the experiments on quartz, we met with the appearance of liquid inclusions in mobile state, so frequent if one may not say constant in granites, quartzes and gneiss. We (see Figure 11) here see a similarity of results tending to prove a similarity of conditions of genesis from the viewpoint of temperatures and pressures. Moreover, it is to be noted that with the densities of rocks which, taking into account chemical composition and compressibility , must range from 2.5 to 4, and with a geothermic gradient which may vary from 1° per 15 m of depth to 1° per 30 m, the depths included between 10.000 and 20.000 m realize the temperatures and the pressures to which those of our experiments approach. It is at these depths that granites appear capable of being produced.

Artificial metamorphism of rocks

Such results led us quite recently to subject small pieces of rock to reheatings under pressure in bombs, with accompaniment of water alone or of water and alkalis, in order to try to realize an artificial metamorphism. Up to the present time the rocks subjected to these experiments have been a chloritoschist quite largely crystalline, a fine calcareous schist, a clay, a conglomerate with small quartz pebbles, some microcline, with specks of mica, in a calcareous cement.

After reheatings of 12 days at 600° C. these rocks observed in thin sections showed abundant crystalline neogeneses, produced « in situ. » In the chloritoschist formed principally of clinochlore and of grains of hematite, there was produced white mica, spinels, and a mineral of high refraction and bi-refringence reminding one of epidote ; these transformations took place at the boundaries of the hematite and of the clinochlore and in the planes of cleavage of the latter. (See Figures 12 and 13).

In the fine schist, the agglomerates of calcite were partially transformed into a mineral resembling augite; there was also produced on the surface of the sample a glaze of fine needles extending obliquely which under X rays gave a diagram of anorthite.

Plastic clay originally rich in halloysite was transformed into a brittle clay rich in sericite, with spots of crystals of calcite and, on the surface, crusts of fine crystals of probable aegerite augite.

The conglomerate of calcareous cement was found covered by a thick felting of fine crystals, penetrating deeply in geodes. In a thin section, it showed itself to be tranformed in places into a real epidote.

The process of metamorphism here results clearly from the penetration of the gases under high pressure which, in the case of the holocrystalline rocks, proceed along the joints of the minerals themselves and along the planes of cleavage; the new crystallizations start from these joints and progressively penetrate the original crystals. In the case of the rocks with fine particles, surrounded by colloidal matters, these gases are propagated everywhere into the rock and absorb the latter. The crystalline neogeneses appear a little everywhere without the possibility of distinguishing the paths of advance.

In the two cases, the rocks subjected to the experiments showed themselves capable of being entirely penetrated by the gases under high pressure; the action of water alone is manifest but nevertheless weak during the relatively short duration of these experiments; that of water accompanied by alkalis was much more intense.

Conclusions

I believe that our experimental results of genesis of minerals by pneumatolysis under high pressures and of artificial metamorphism furnish a certain confirmation of the theories which have attributed the metamorphism of contact of rocks and the regional metamorphism principally to penetration of gas and steam together with increase in temperature. The neogeneses « *lit par lit* » and those « *by superposition* » formerly distinguished in contact metamorphism may be compared to the neogeneses which we found at the joints of the chloritoschist studied above and to those formed in all parts of the clay. It seems to be certain, therefore, that minerals existing in the heart of rocks can undergo metamorphism, with or without the introduction of new elements, and taking place without the rocks being subjected to actual remelting.

Thus micropyrotechnics has permitted the realization of syntheses of minerals and of metamorphism of rocks under conditions of pressure and of temperature which approach those under wich granite must have been formed. I believe it to be capable of furnishing new data to the information already so noteworthy that has hitherto been accumulated particularly by the learned physicists of the Geophysical Laboratory of Washington and by van NIEUWENBURG.

PL. I.

MICHEL-LÉVY. — *Emploi des explosifs pour la synthèse par pneumatolyse des minéraux des roches de profondeur (granite). Métamorphisme artificiel.*

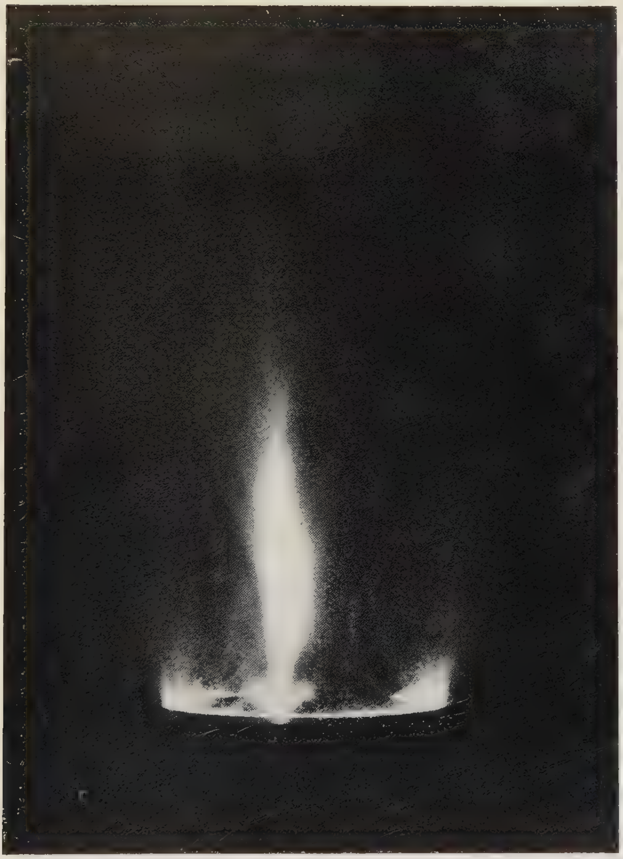


Fig. 1. — Colonne lumineuse provoquée par la rencontre des deux trains d'ondes de choc, ans la détonation du mélange à combustion complète de tétranitromethane et de toluène) cm^3, 4) introduit dans la rigole circulaire d'un bloc cylindrique de laiton de 4 cm de diaètre. Air libre. Diaphr. F : 32.

(Luminous column caused by the impact of two trains of shock waves, in the detonation f the mixture having complete combustion of tetranitromethane and toluene (0.4 cubic cm), laced in the circular trench of a cylindrical block of bronze 4 cm in diameter).

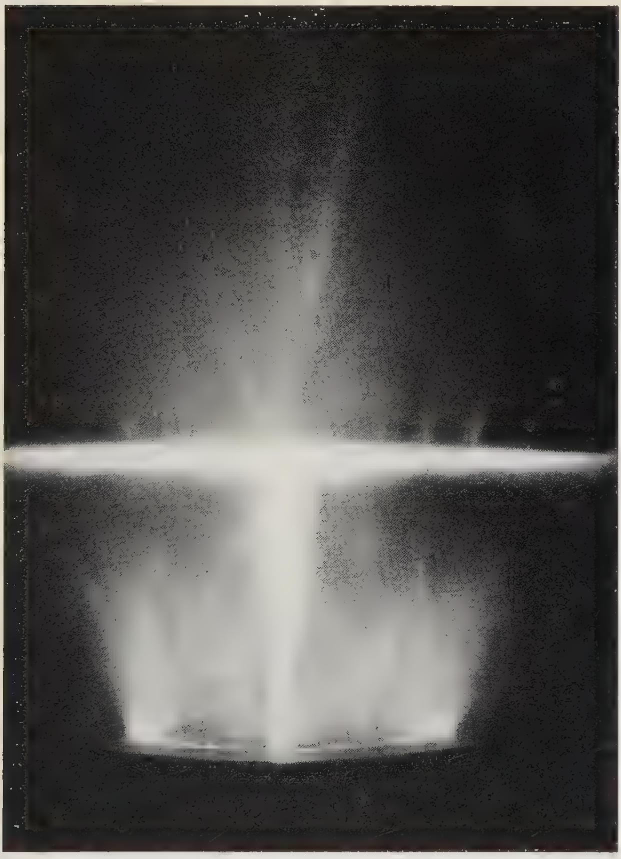


Fig. 2. Rencontre par une feuille de papier des ondes de choc ; luminosité provoquée ous cette feuille. Air libre. F : 32.

(Interference by a sheet of paper of shock waves ; luminosity caused by this sheet).

. Michel-Lévy. — *Emploi des explosifs pour la synthèse par pneumatolyse des minéraux des roches de profondeur (granite). Métamorphisme artificiel.*

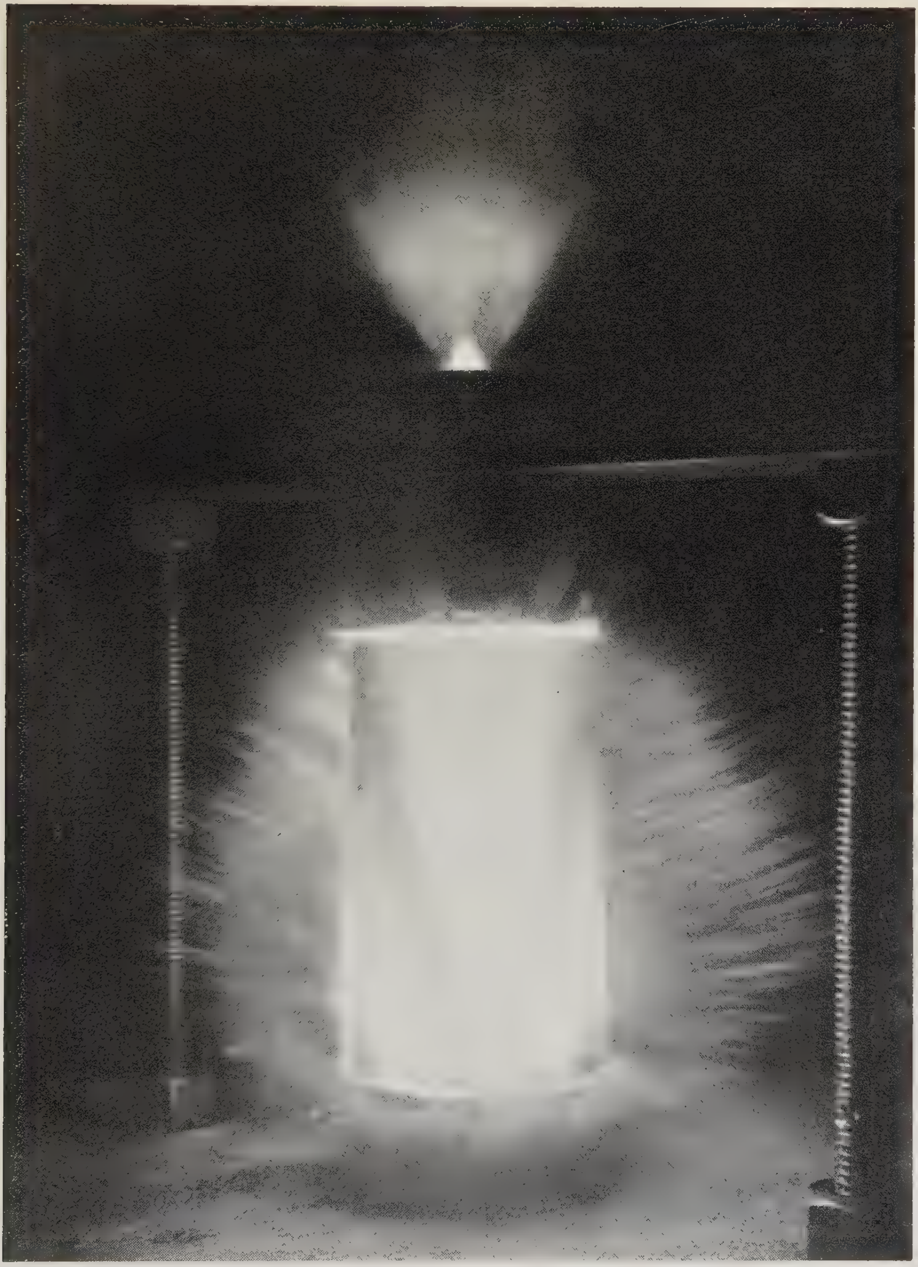
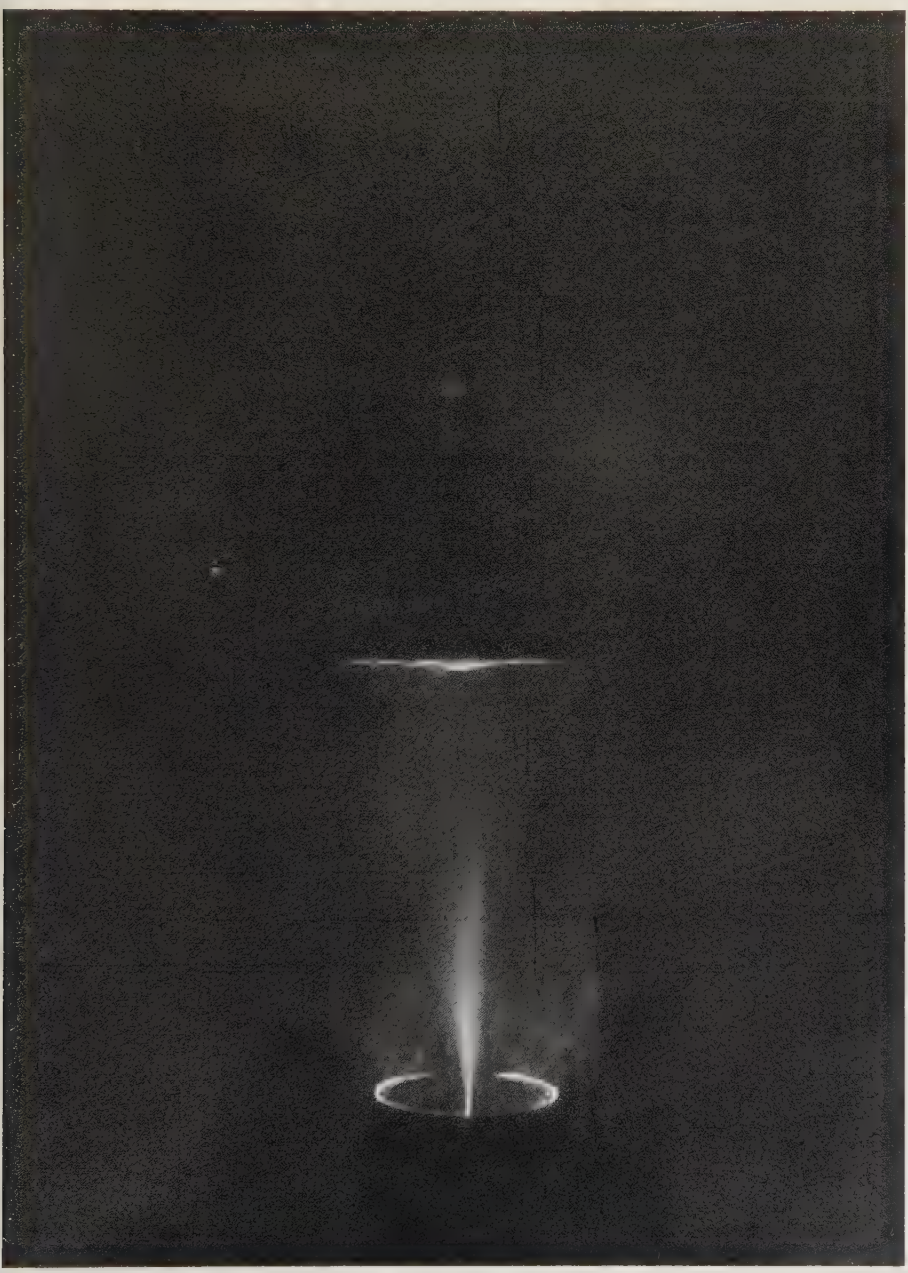


Fig. 3. — Effets lumineux dans une chambre en cellophane, remplie d'argon. Le chapeau upérieur du montage est un cône en laiton, surmonté d'un tube. F: 32.

(Luminous effects in a chamber of cellophane, filled with argon. The upper cover of the ounting is a hollow cone of bronze, capped by a tube).

Michel Lévy. — *Emploi des explosifs pour la synthèse par pneumatolyse des minéraux des roches de profondeur (granite). Métamorphisme artificiel.*



. 4 — Effets lumineux dans une chambre en cellophane remplie d'acide carbonique. F: 32.
(Luminous effects in a chambre of cellophane filled with carbonic acid).

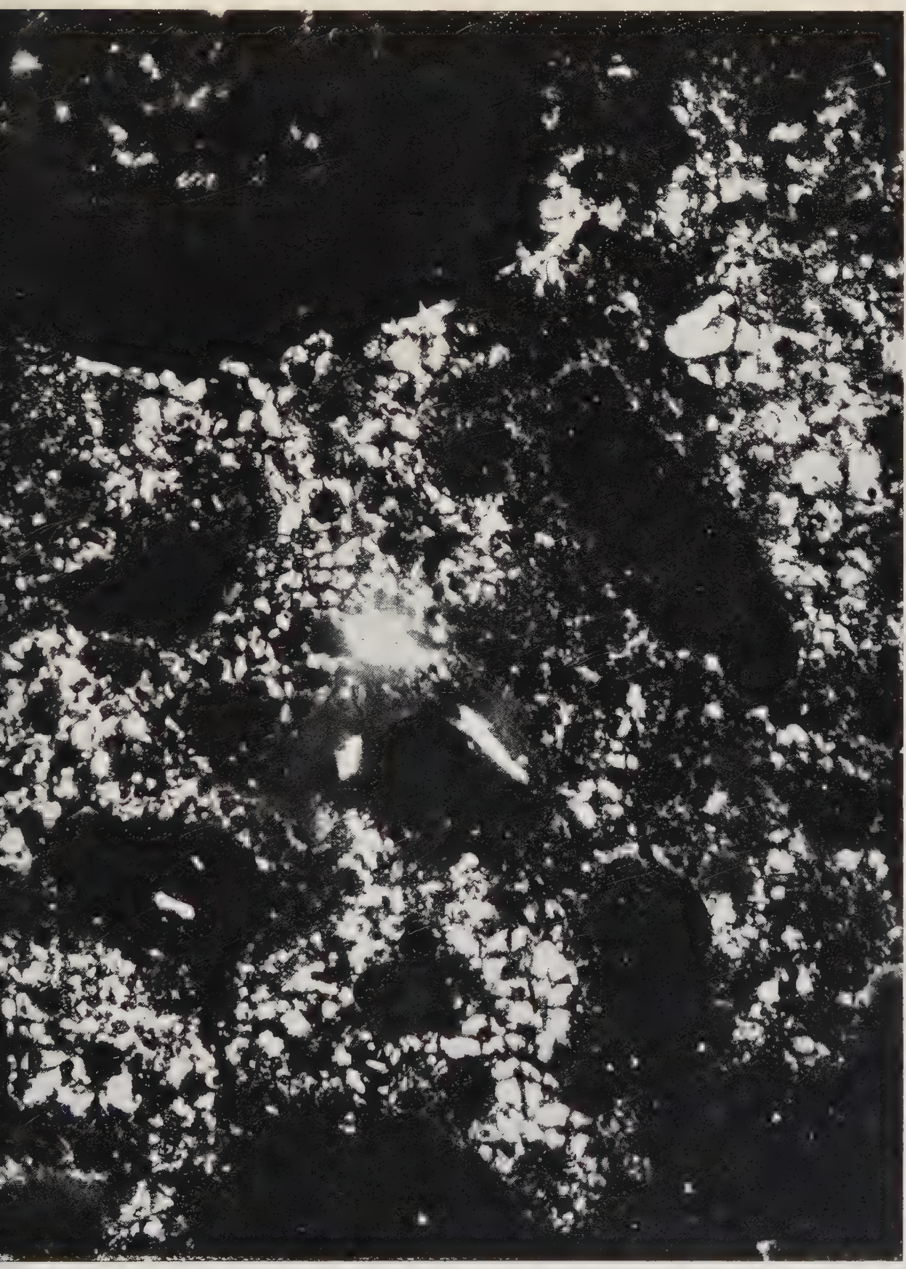


Fig. 5. — Sphérolites d'orthose en plaque mince, entre nicols croisés. Gross. × 75.
(Spherolites of feldspar in thin section, between crossed nicols).

PL. VI.

Michel-Lévy. — *Emploi des explosifs pour la synthèse par pneumatolyse des minéraux des roches de profondeur (granite). Métamorphisme artificiel.*

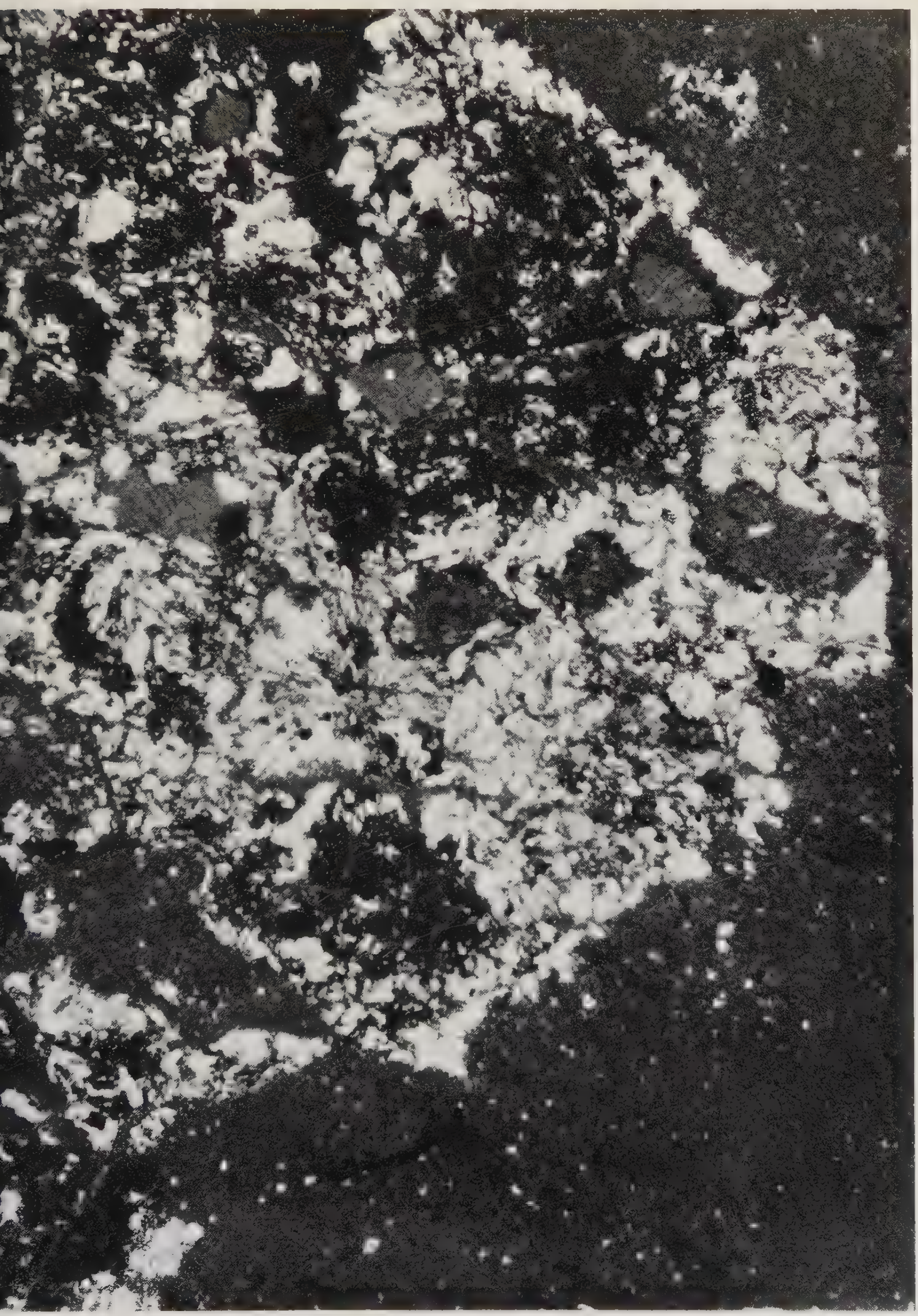


Fig. 6. — Sphérolites d'albite en plaque mince, entre nicols croisés. Gross. × 100.
(Spherolites of albite in thin section, between crossed nicols).

MICHEL-LÉVY. — *Emploi des explosifs pour la synthèse par pneumatolyse des minéraux des roches de profondeur (granite). Métamorphisme artificiel.*

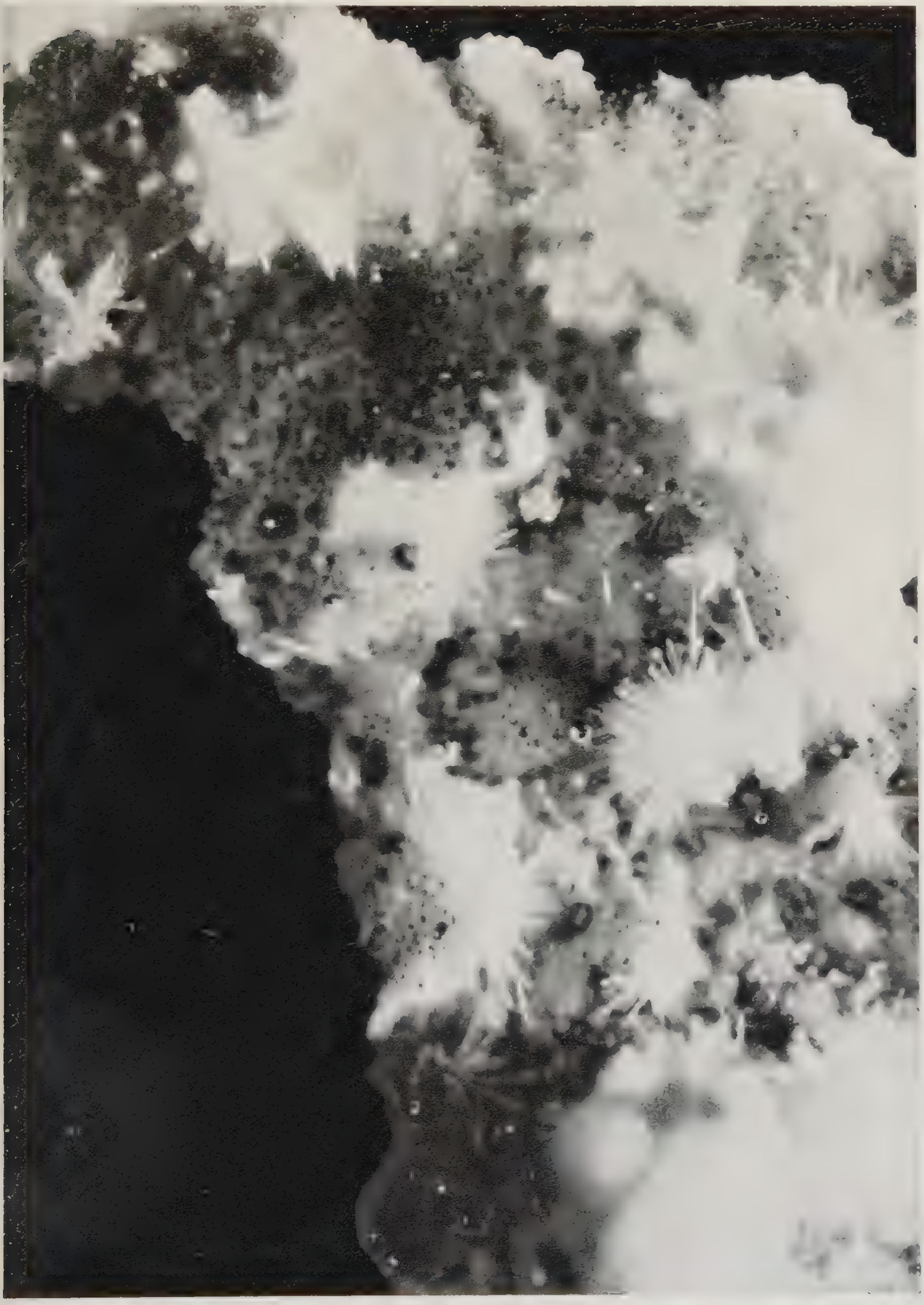


Fig. 7. -- Glomérules d'anorthite vus par réflexion. Gross. × 60.
(Glomerules of anortite seen by reflection).

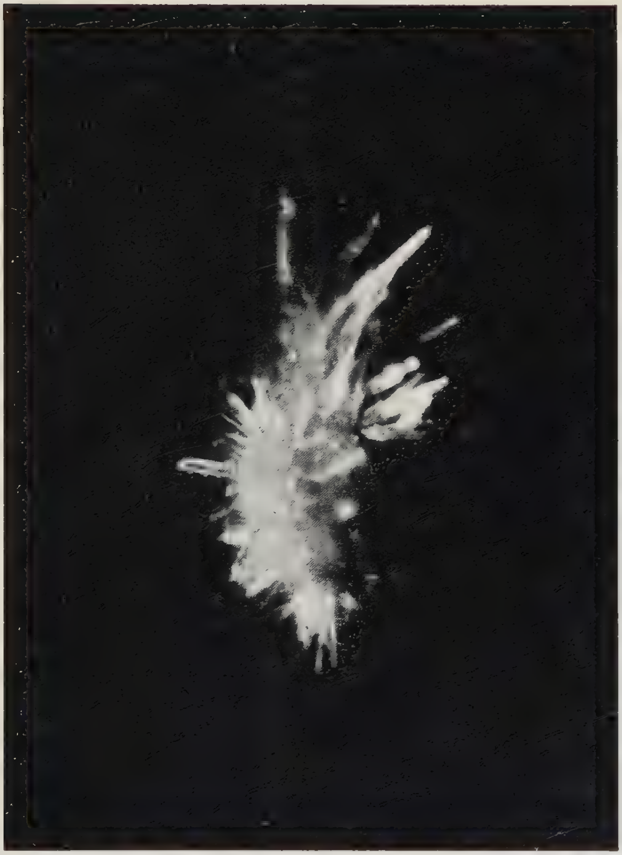


Fig. 8. — Groupement en rosettes de cristaux d'anorthite. Gross. × 60.
(Groups of rosettes of anortite).

MICHEL-LÉVY. — *Emploi des explosifs pour la synthèse par pneumatolyse des minéraux des roches de profondeur (granite). Métamorphisme artificiel.*

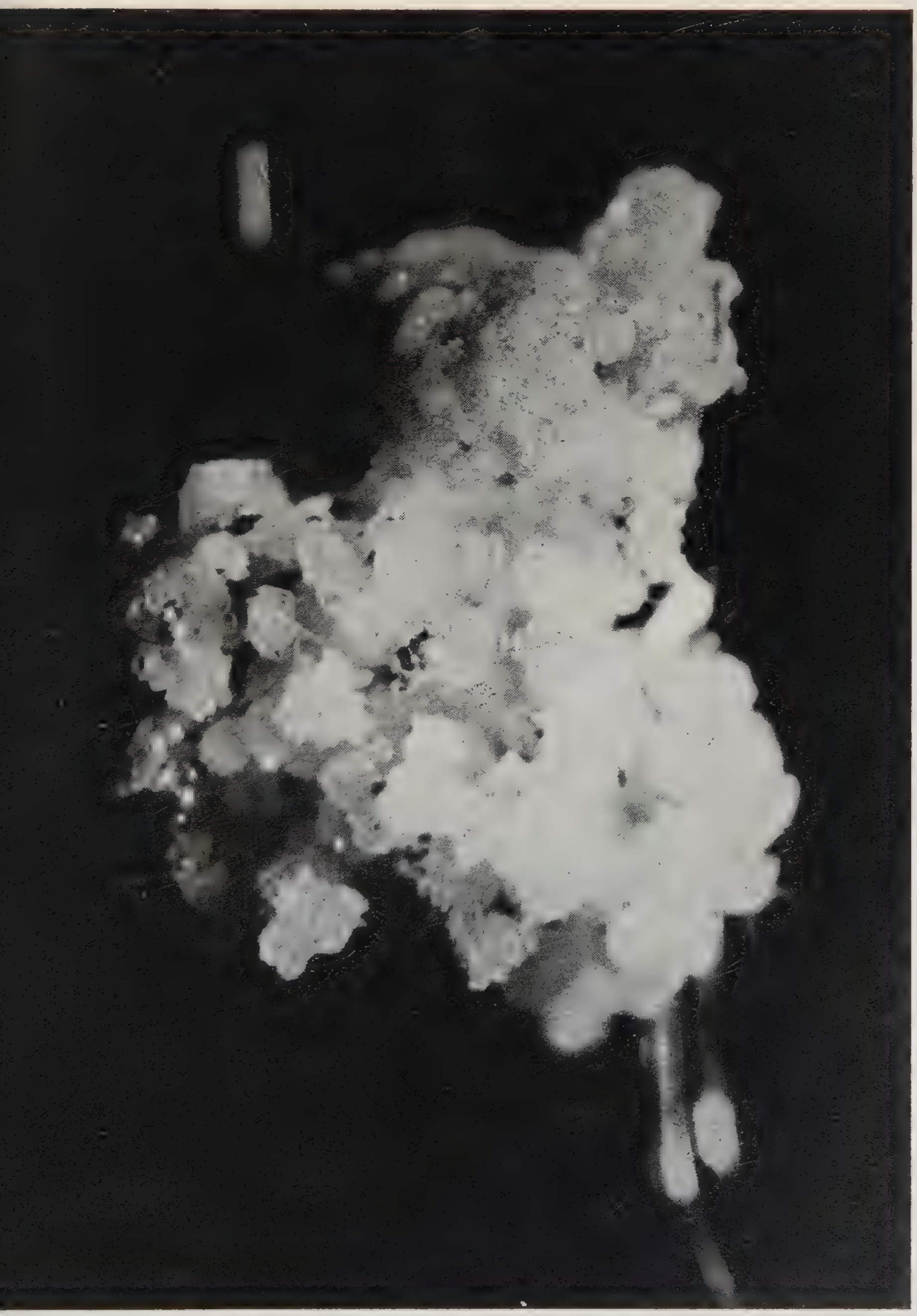


Fig. 9. — Glomérules associés de prismes de quartz vus par réflexion. Gross. × 100.
(Associated glomerules of quartz prisms seen by reflection).

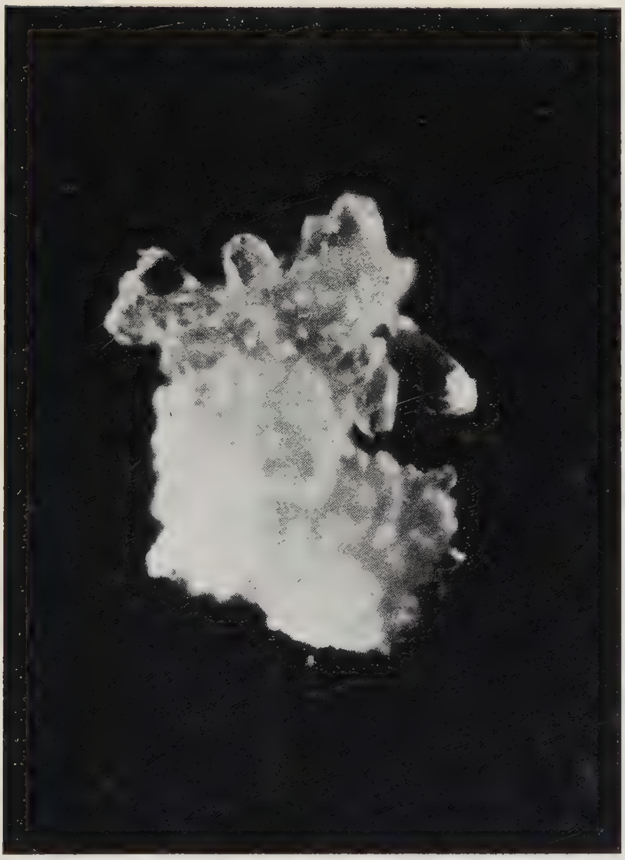


Fig. 10. — Groupement de prismes bipyramidés de quartz (par réflexion). Gross. × 105.
(Groups of bipyramided prisms of quartz — by reflection).

PL. XI.

ICHEL-LÉVY. — *Emploi des explosifs pour la synthèse par pneumatolyse des minéraux des roches de profondeur (granite). Métamorphisme artificiel.*

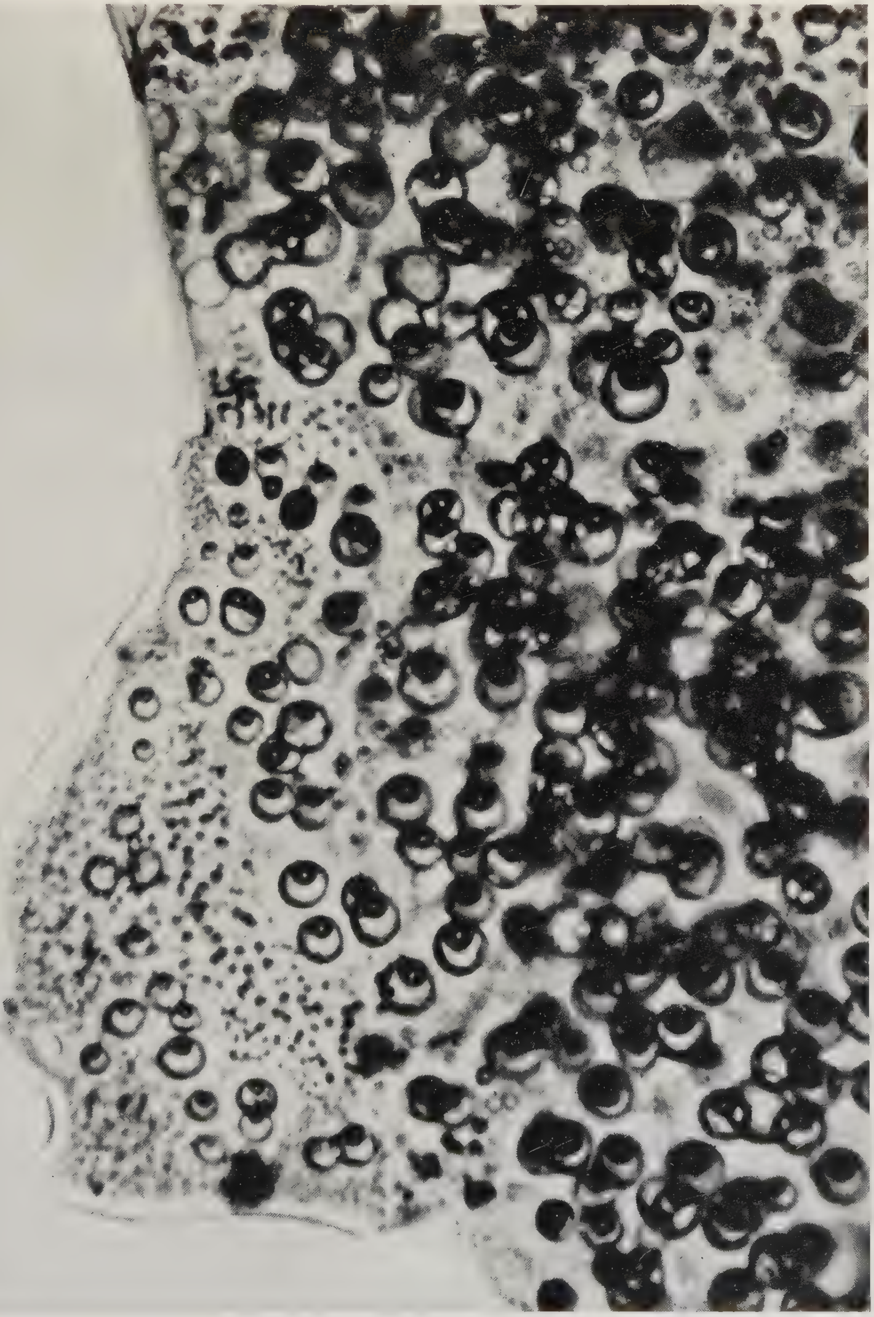


Fig. 11. — Inclusions liquides à libelle mobile dans un residu accompagnant le quartz. Ce nier contient également de telles inclusions. Gross. × 160.

(Liquid inclusions in mobile state in a vitreous residue accompanying quartz. This latter contains such inclusions).

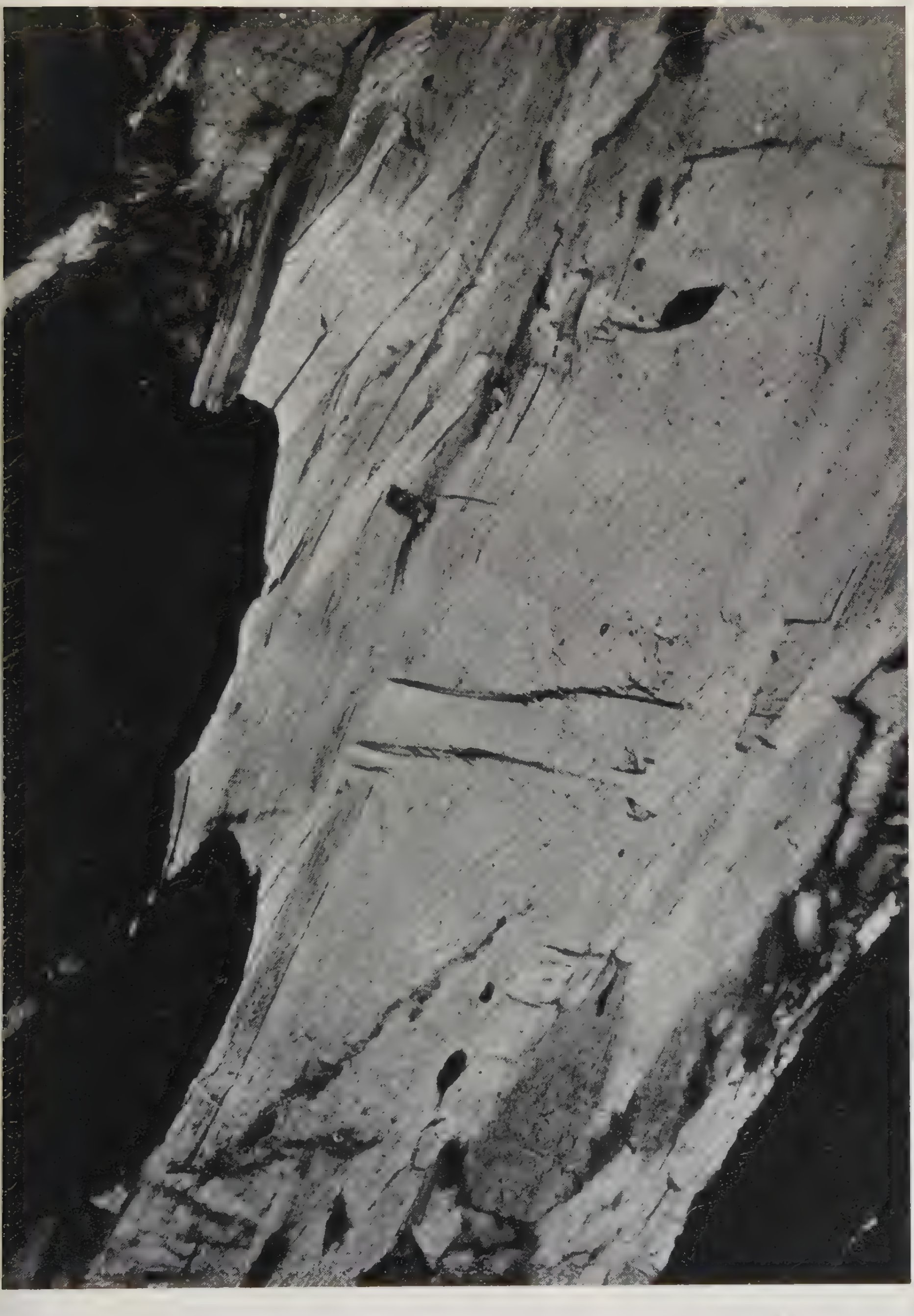


Fig. 12. — Chloritoschiste en plaque mince, nicols croisés, avec clinochlore et oligiste moin). Gross. × 115.

(Chloritoschist in thin section, crossed nicols, with clinochlore and specular ion).

MICHEL-LÉVY. — *Emploi des explosifs pour la synthèse par pneumatolyse des minéraux des roches de profondeur (granite). Métamorphisme artificiel.*

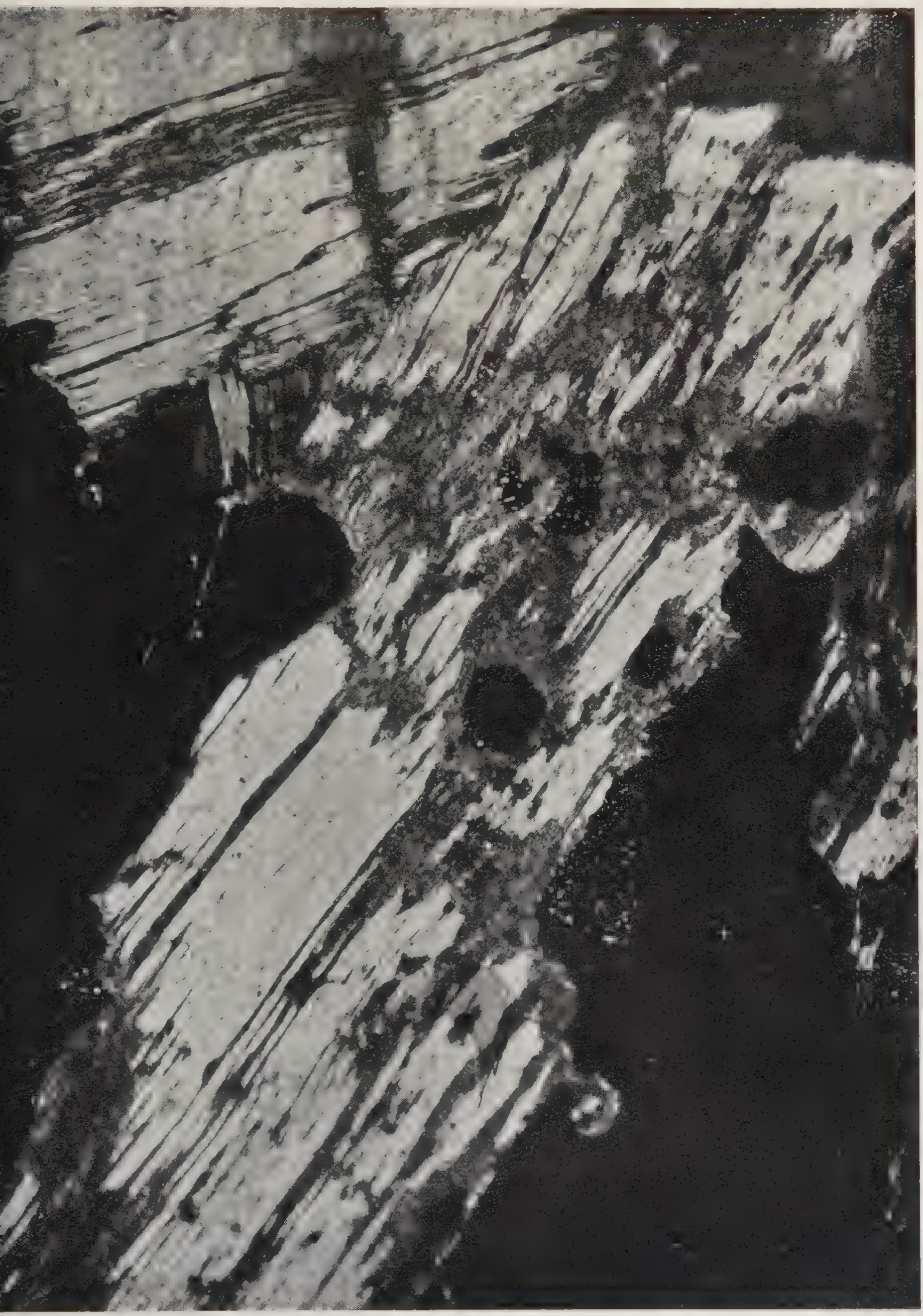


Fig. 13. — Le même chloritoschiste après 12 jours de recuit dans la bombe à 600°, sous 3000
000 kg de pression par cm², avec eau et potasse. Naissance dans le clinochlore de mica blanc,
spinelles et d'un minéral à haute refringence (épidote?) Nicols croisés. Gross. × 115.
(The same chloritoschist after 12 days of reheating in the bomb a 600° C under 3000 to
0 kg of pressure per square cm, with water and potash. Development in the clinochlore of
te mica, spinels, and a mineral of high refraction (epidote?). Crossed nicols).

FRANCESCO SIGNORE

Rapporto sull' attività del " Bureau International de Volcanologie „

Prima di parlarvi del funzionamento del Bureau durante questo triennio, permettetemi di ringraziare il nostro Presidente, Prof. Michel-Lévy, per la sua gradita visita fatta al Bureau nell' aprile del 1937; visita che ci permise, durante le varie escursioni ai vulcani partenopei, un utile e fattivo scambio di idee, che è continuato cordialmente durante tutto il triennio.

In questo triennio ebbi ancora il piacere di accompagnare, nella visita ai vulcani della zona di Napoli, il Colonnello Agosthiño, Direttore dell'Osservatorio delle Azzorre, il Presidente dell'Associazione di Metereologia dell'U.G.G.I., Prof. Chapman, il Vice-Presidente della Sezione di Vulcanologia dell'Unione geofisica americana, Prof. Knopf, e la sua gentile Signora, la Signorina Dott. Boisse de Black, della Sorbonne, il Prof. Bossolasco, dell' Università di Messina, e varie comitive di studiosi , stranieri ed italiani, che si erano rivolti al Bureau per avere informazioni e facilitazioni per la visita del Vesuvio e dei Campi Flegrei.

Mi auguro che queste visite diventino ancor più frequenti, poichè esse serviranno a cimentare sempre più la amicizia fra gli studiosi.

Il Bureau è lieto di mettere in relazione fra loro i varî studiosi di vulcanologia, di facilitare la visita dei vulcani italiani, di collaborare con i vari istituti, inviando notizie bibliografiche, materiale vulcanico per ricerche o per collezioni, consigliando ricerche da intraprendere e, all'occasione, accordando anche sussidi.

In questo triennio, infatti, oltre ad inviare campioni varî per musei e collezioni, si è provveduto a mandare al Prof. Rothé, Segretario dell' Associazione di Sismologia dell' U.G.G.I. e Direttore dell' Istituto di Fisica del Globo di Strasburgo, varî prodotti del Vesuvio per lo studio della radioattività. Sono stati concessi dei sussidi, uno di franchi francesi 5.000 al geologo Gèze per lo studio dei vulcani nel Cameroun e in Nigeria e un altro di lire italiane 2.000 al Dr. Mirigliano dell' Istituto di Geologia della R. Università di Napoli, per completare i due lavori : *Studio dell' eruzione del Vesuvio nel 79 d. C.*, e *Revisione geologica e petrografica del Somma-Vesuvio.* I lavori saranno pubblicati integralmente nel Bulletin Volcanologique.

Il Bureau su invito dell' « Institut International de Cooperation Intellectuelle » nominò un proprio delegato nella persona del Prof. B. G. Escher, per trattare le questioni di nomenclatura volcanologica, e allo stesso Prof. Escher fu affidato il compito di rappresentare l' Associazione nel « Committee on science and its social relation (C.S.S.R.) ».

Altre notizie relative all'attività del Bureau in questi tre anni sono state riportate nei varî Bollettini.

Nel triennio sono stati pubblicati cinque volumi del « Bulletin Volcanologique », che contengono in complesso trentadue lavori, ricchi di tavole, carte a colori e figure, illustranti vulcani e fenomeni inerenti al vulcanesimo. Questa nuova serie del « Bulletin Volcanologique » ha riscosso il plauso degli studiosi delle varie nazioni e sono state richieste molte copie supplementari. Sono state cedute anche copie a pagamento per un ammontare di circa tremila lire italiane.

Agli autori sono stati offerti in omaggio 100 estratti, invece di 50 come per il passato. Però in complesso possiamo dire che non sono stati molti gli studiosi di vulcanologia che hanno risposto all' invito di collaborare nel « Bulletin » : non sto ad enumerare le lettere spedite, la maggior parte delle quali rimaste senza risposta, perchè tale numero risulta dalle spese postali, che sono riportate nel rendiconto finanziario dettagliatamente.

Molti studiosi, che avevano promesso dei lavori, non hanno, quantunque ripetutamente sollecitati, mantenuta la promessa.

Sarebbe molto utile per il progresso della vulcanologia, che gli studiosi dei varî distretti vulcanici e i direttori degli Osservatori vulcanologici inviassero periodicamente notizie, anche succinte, sui vulcani della loro zona. La stessa preghiera rivolgo ai Ministeri della marina delle varie nazioni, affinchè vogliano ridisporre l'invio delle notizie sulle eruzioni sottomarine rilevate dai registri di bordo. In questo triennio non ne sono giunte!

Nel 1934-35 furono eseguite al Vesuvio due campagne gravimetriche, le quali misero in evidenza una deficienza presso Boscoreale; ora, continuando il Vesuvio nella stessa attività effusiva iniziatasi nel 1933, sarebbe opportuno ripetere le misure per accertare se in questo quadriennio si sono avute delle variazioni. Per tali ricerche prego l'Associazione di voler concedere un contributo di lire italiane 20.000, per intraprendere il lavoro nell'estate del prossimo anno.

Dietro invito del Presidente chiesi ai componenti del Bureau delle proposte per compilare il catalogo dei vulcani; ebbi due schemi, uno del Prof. Escher e l'altro del Dott. Richey. Quest'ultimo è stato proposto dal Comitato inglese di Vulcanologia. I due schemi, di cui si può prendere visione, in generale rispondono; quello inglese è più completo; ad esso però bisognerà aggiungere anche il testo in italiano e in tedesco.

Per il catalogo dei vulcani, come per la Bibliografia vulcanologica, di cui si vuole intraprendere la pubblicazione, proporrei di invitare a collaborare gli studiosi competenti dei varî vulcani e di stabilire per essi un adeguato compenso.

Unitamente a questa relazione presento il rendiconto finanziario e auguro un proficuo lavoro.

Traslation

FRANCESCO SIGNORE

Report on the activities of the Bureau International de volcanologie from 1936-1939.

Before speaking to you about the activities of the Bureau during the period of three years, I wish to thank our President, Prof. Michel-Lévy, for the kind visit which he paid to the Bureau in April 1937. Due to this visit, it has been possible for us, during the various excursions to the volcanoes in the Neapolitan region, to have a useful and fruitful exchange of ideas which has continued during the entire period of three years.

In the same period I had also the pleasure of accompanying to the Neapolitan volcanoes: Col. Agostinho, Director of the Observatory of the Azores, Prof. Chapman, President of the Association of Meteorology of the International Union of Geodesy and Geophysics, the Vice President of the Volcanology Section of the American Union of Geodesy, Prof. and Mrs. Knopf, (Miss) Dr. Boisse de Black of the Sorbonne, Prof. Bossolasco of the University of Messina, and various groups of students, both foreign and Italian, who asked the Bureau to give them information and facilitate their visit to Vesuvius and its immediate surroundings (Phlegrean Fields).

I hope that these visits will continue to increase in number as they will also help to establish friendships between the students.

In this connection the Bureau will be glad to establish contacts between the various students of volcanology, to provide facilities for visits to the volcanoes in Italy, to collaborate with the different institutes by sending them bibliographical notes, volcanic material for purposes of research or collections, giving advice as to the research to be made, and, if the occasion warrants, it may even provide for subventions.

In fact, during the above mentioned period of three years, besides various samples wich were sent to museums and collections, provision was made to supply Prof. Rothé, Secretary of the Association of Seismology of the International Union of Geodesy and Geophysics and Director of the Institute of Geophysics at Strasbourg, with a series of products of Vesuvius for the study of radio-activity. Subsidies have been provided, one in the amount of 5000 French francs for M. Geze, the geologist, for purpose of making studies on the volcanoes in Cameroon and Nigeria, and another of 2000 Italian lire for Dr. Mirigliano of the Institute of Geology of the University of Naples in order to complete the two following works : « Study on the eruption of Vesuvius in 79 A. D. » and « Geological and Petrographic revision of the Somma-Vesuvio ». The complete works will be published in the Bulletin Volcanologique.

At the request of the Institut International de Cooperation Intellectuelle, the Bureau appointed Professor G. B. Escher as a special delegate for the treatment of the questions pertaining to the nomenclature of Volcanology, and the latter was also entrusted with the representation of the Association on the Committee on Science and its social relations (C. S. S. R.).

Further information relative to the activities of the Bureau in these three years has been published in the various Bulletins.

During the above period of three years five volumes of the Bulletin Volcanologique have been published, containing altogether 32 reports, rich in illustrations, maps in color, figures, showing the volcanoes and phenomena inherent to volcanism. This new series of the Bulletin Volcanologique has met with approval of the students of the various countries and many additional copies have been requested. Copies have also been given out for payment amounting to about 3,000 Italian lires.

The authors have been awarded 100 extracts instead of 50 as was customary in the past. But in general we cannot say that there was a great number of students of Volcanology who have accepted the invitation to cooperate with the Bulletin. I do not wish to enumerate the letters that have been mailed, the majority of which remained unanswered, as that number may be seen from the amount of postage accounted for in detail in the Financial Report.

Many students who have promised to submit reports did not keep their promises although they were asked repeatedly to do so.

It would be very helpful for the progress of Volcanology if the students of the various volcanic districts and the directors of the Volcanological Observatories sent us reports regularly, even though they may be limited to the volcanoes of their areas. I wish to address the same request to the Naval Ministries of the different countries, asking them to be good enough to send again the reports of submarine eruptions as they appear on the Naval Registers. In the said period of three years none have been received.

In 1934-35 two gravimetric campaigns were undertaken in the Vesuvius area, which reveal a deficiency near Boscoreale. As Vesuvius continues in the same effusive activity as started in 1933, it would be appropriate to repeat the measurements in order to ascertain whether there have been any changes in this period of four years. For research in this connection, I beg the Association to be good enough to grant a contribution of 20,000 Italian lire in order to make it possible to initiate these activities in the summer of next year.

On the request of the President, I asked the staff of the Bureau for suggestions relative to the compilation of the Catalogue of the Volcanoes. I received two drafts, one from Prof. Escher, and the other from Dr. Richey. The latter has been proposed by the English Committee on Volcanology. These two drafts which are open for inspection agree in general. It is, however, necessary to add to the latter, the text in Italian and German also.

For the Catalogue of Volcanoes, as well as for the bibliography on Volcanology, the pubblication of which has been contemplated, I should like to suggest that the competent students of the various volcanoes be invited to collaborate, and that an adequate remuneration be established for them.

Together with this report I am presenting the Financial Statement, wishing that the work may prove beneficial.

ASSOCIATION INTERNATIONALE DE VOLCANOLOGIE

1er janvier 1936 - 31 décembre 1938

RECETTES

	Francs-or suisses	*Lire*	*Francs-or suisses*
Actif au 1/1/36		197.432,90	31.833,65
Reçu du Secrétaire général :			
12/11/36	752,00		
25/6/37	3.007,70		
1/4/38	3.564,13		
7/7/38	1.130,00		
15/7/38	3.007,70		
12/12/38	6.015,50		
24/12/38	2.522,97		
			20.000,00
Intérêts Ital.			772,99
Intérêts Angl.			76,26
Vente des Bulletins.			320,23
Total.			53.003,13

PAYMENTS

		Francs-or suisses
Bulletin volcanologique (impression, clichés, traductions, expédition, etc.		7.519,93
Contributions :		
Raz de Marée	1.130,00	
Accordées par le Bureau	134,36	
		1.264,36
Transports, voyages, pourboires, frais de correspondance		950,96
Bureau, dépenses (achats de meubles, papéterie, reliure, frais Congrès d'Edimbourg)		1.313,20
Actif au 31/12/38		41.954,68
L. 142.970,32 £ 1256 18*s.* 8*d.*		
Total		53.003,13

RAPPORT DE LA COMMISSION DE FINANCE

Acting President L. A. ADAMS
Association of Volcanology

Dear Sir,

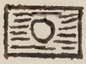
Your committee has examined the books of the Secretary General, Dr. Signore, and reports that they appear to be correct.

Signed:
Francis Birch
Eugene Callaghan

B. G. Escher

Esquisse
our les feuilles d'un catalogue des vol-
ans actifs et récents et des volcans éteints
à partir du tertiaire.

Outline
for the leafs of a catalogue of the active
recent volcanoes and the extinguished vol-
canoes since the tertiary.

Éteint (Extinguished)	État solfatarien Solfataric stage	Actif (Active)
		

ituation géographique :
Geographic situation)

ongitude : . . . .
de Greenwich)

atitude : . . . .

'ays ou île :
Land or isle)

Nom du volcan : . . . .
(Name of volcano)

Synonymes : . . . .

Nom du cratère : . . . .
(Name of crater)

Synonymes : . . . .

Produits (Products)

'aves :
Lava)

'ombes :
Bombs)

endres :
Ashes)

roduits secondaires :
econdary products)

étrographie (Petrography)

Éruptions :

↑ Explosions verticales (Vertical explosions)

→ Nuées ardentes (horizontales) (Glowing clouds)

▬ Lac de lave (Lava lake)

〰→ Coulée de lava (Lava flow)

⌒ Cumulovolcan (Lava plug)

Λ Aiguille (Spine)

⇡ Explosion phréatique (Phreatic eruption)

Date	Sorte (Kind)	Date	Sorte (Kind)

Continuation de la liste des éruptions : (Continuation of the list of eruptions)				Faits divers. (Sundries)
Date	Sorte (Kind)	Date	Sorte (Kind)	

emps d'activité du volcan éteint:
(Time of activity of extinguished volcano):

Holocène (Recent) . . . . Pleistocène	. . . . .
Pliocène . . . . Miocène	. . . . .
Oligocène . . . . Eocène	. . . . .

Chronologie plus exacte:
(More exact definition of time):

Morphologie (Morphology)

arte du volcan avec cratères et solfatares.
(Map of volcano with craters and solfataric fields).

Échelle (Scale):

ibliographie des ouvrages principaux:
(Bibliography of the most important works):

PROPOSED CATALOGUE OF VOLCANOES OF THE WORLD

The following slight modifications of Professor Escher's scheme are suggested the **British Sub-Committee for Volcanology**.

1. It is proposed that the Catalogue should be restricted to Active and Dorma Volcanoes.

2. Active and Dormant are defined as follows:

Active: volcanoes known to have been in eruption in historic times.

Dormant: volcanoes showing solfataric activity at the present day, but with historic record of eruption.

Any volcano not falling within either of the above definitions is considered to extinct, even if its original form is perfectly preserved. A separate catalogue might compiled for these.

3. A modified plan for pages of Catalogue is appended.

4. The list of symbols for the kinds of eruptions given in Prof. Escher's schem is modified and enlarged, as follows:

○	Éruption provenant d'un cratère central	(Crater eruption)
Φ	» » » » adventif	(Parasitic crater eruption)
═	» » » fente	(Fissure eruption)
╪	» » » » adventif	(Parasitic fissure eruption)
↑	Explosions normales	(Normal explosions)
⟶	Explosions produisant des nuées ardentes	(Explosions producing « nuées a dentes
⤳	Éruption d'une coulée de lave	(Eruption of lava flow or flows)
◡	Éruption dans un lac de lave	(Lava-lake eruption)
⌓	Formation d'un dôme	(Extrusion of lava-dome in crater)
Δ	Formation d'une aiguille sur le dôme	(Formation of spine on crater-dome)
⇡	Explosions phréatiques	(Phreatic explosions)
⊼	Éruption sous-marine	(Submarine eruption)
≈>	Formation de coulées boueuses	(Mud-flow eruption)

SCHEME FOR PAGES OF CATALOGUE

om du volcan: . . . .
(Name of volcano)

ynonyms: . . . .

om(s) du cratère(s): . . . .
Name(s) of crater(s)

ynonymes : . . . .

ype du volcan: . . . . . e. g. Shield
(Type of volcano)

Pays ou île . . . .
(Contry or island)

Situation géographique:
(Geographical position)

Latitude . . . .

Longitude. . . . .
(de Greenwich)

Âge. . . . . . . e. g. Pleistocène-Recent

Classe . . . . e. G. Active
(Class)

ate	Sorte d'éruption (Kind of eruption	PRODUITS (Products)				Faits divers (Remarks)
		Laves (Lavas)	Bombes (Bombs)	Cendres (Ashes)	Produits sécondaires (Secondary products)	
		To include type, e g. ropy, and composition, e. g. olivine-basalt	To include type and composition	To include type and composition		

Pétrographie (Petrography)

Topographie et Morphologie (Topography and Morphology)

To include: Carte du volcan avec cratères et solfatares
(Map of volcano and solfataric fields)

Bibliographie des ouvrages principaux
(Bibliography of the most important works)

TOM. F. W. BARTH

Pristine and Contaminated Rock Magma and Thermal Water

(With 2 text-figures)

I

Rock magmas are complex silicate melts intimately associated with a gas phase fed by emanations from the molten magma. Since magmas themselves and their emanations are rarely accessible to direct investigation, their composition must be inferred from the study of certain natural products in the formation of which magmatic agents have participated. Such products are e. g., rocks, incrustations, and thermal waters.

The material of an igneous rock or of a hot-spring is in general not derived from primary magmatic sources alone. In the molten magna as well as in the associated gas phase contamination occurs in consequence of assimilation of adjacent sedimentary material. The resulting igneous rock, or the resulting hot spring may therefore in many cases contain a large percentage of material of secondary character, i. e , material which did not belong to the primary magmatic phases but which later was incorporated by a process of reaction and assimilation. How active such processes have been is an important and much discussed petrological question.

It is the object of the present paper to point out certain criteria that apparently indicate the degree of contamination to which rock magmas or thermal waters have been subjected.

II

The study of igneous rock provinces has demonstrated the existence of alkaline rock series and of sub-alkaline rock series. But it should be borne in mind that this two-fold division is arbitrary in so far as there is a gradual transition between the two groups. It has been a general tendency among petrographers to regard the common sub-alkaline rocks as direct derivatives of primitive magmas, whereas the alkaline rocks were looked upon as more distant products derived from sub-alkaline rocks by more or less complicated processes of differentiation or assimilation. But during the last few years various petrologists have come to the opposite conclusion. My own contention is that the mildly alkaline rock suites, generally speaking, are directly derived from primitive rock magmas through fractional crystallization, and that the sub-alkaline rock suites, as encountered for example in the circum-Pacific zone of folding, are derived from primitive magmas through contamination (and subsequent crystallization) [1]. Thus, in a general way, one can say that the more subalkaline the rock suite, the more contaminated the corresponding magma.

Now we shall proceed to show that the so-called alkali-lime index can be considered a measure of the subalkaline character of a rock suite. Following Harker, Peacock [2] has offered for consideration a classification of rock series based on the alkali-lime index the value of which is determined as follows:

---

[1] Several arguments in favour of this, or similar, ideas have been advanced in the following papers: Barth, T. F. W.: *Crystallization Process of Basalt.* Am. Jour. Sci. 31, 321-351, 1936; Rittmann, A.: *Vulkane und ihre Tätigkeit.* Stuttgart 1936; Wegmann, C. E.: *Geological Investigations in Southern Greenland.* Medd. om Grønland Bd. 113, Nr 2, 1938 especially p. 148; Kennedy, W. Q. and Anderson, E. M.: *Crustal Layers and the Origin of Magmas.* Bull. volcan. Ser. 2, vol. 3, 23-82, 1938; Barth, T. F. W. and Holmsen, Per: *Rocks from the Antarctandes and the Southern Antilles.* Norw. Antarctic Exp. Nr 18. Vid. Akad. Oslo, 1939.

[2] Peacock, M. A.: *Classification of Igneous Rock Series.* Jour. Geol. 39, 54-67, 1931.

In an ordinary variation diagram the curves for CaO and for ($Na_2O + K_2O$) always intersect. The value of the abscissa of the point of intersection expressed in terms of percents of SiO_2 is the alkali-lime index. For alkaline rock series this index is around 50, for sub-alkaline rock series it is 60 or more. As a basis for classification this index is in so far ideal as it, corresponding to natural conditions, varies continuously with the continuously changing features of the natural rocks.

I believe that a rock series formed by gradual congealing of a primitive magma must exhibit an alkali-lime index of around 50; and it can be shown that if the primitive magma assimilates sedimentary material, more especially argillite, then the resulting rock series must exhibit an alkali-lime index that is higher than 50 (see BARTH and HOLMSEN, op. cit.) [1]. Hence the following relation: The higher the index the more sub-alkaline the rock series and the more contaminated the corresponding magma.

Fig 1 displays alkali-lime index diagrams (after PEACOCK) for various well-known rock series of the world.

III

Now we turn to the thermal waters. In an excellent paper SHEPHERD [2] has recently shown that volcano gases and gases from lava are always subjected to contamination, and he sees no way in which either the composition or quantity of the primitive magmatic gases can be deduced. In the present paper we shall not try to follow the gases farther back than to the time when they escaped from the magma (or lava). Here we shall use the designation primitive magmatic gases for all gases that boil out of a magma - but the ultimate origin of the gases is left open ; they may have come from the very interior of the earth, or they may represent meteoric gases assimilated by the magma and again expelled.

---

[1] One noteworthy exception is, of course, the assimilation of pure lime stone.

[2] SHEPHERD, E. S.: *The Gases in Rocks and Some Related Problems*. Am. Jour. Sci. *35* A, 311-351, 1938.

There can be no doubt that among the gases given off by a magma steam prevails. But in addition acid gases characteristically occur (CO_2,H_2S etc.), and all emanations therefore display an acid reaction. (Apparently if oxygen is available hydrogen sulfide oxidizes and the waters carrying the emanations will show a ph-value of about 4).

As soon as the emanations leave the magma and begin their percolation upwards to the surface , they will react with the adjacent rocks in a characteristic way. The acids (carbon dioxide and others) attack the rock minerals and extract bases. Thereby the emanations themselves become contaminated and their acid reaction is more or less neutralized. They may mix with large quantities of ground water (or other waters of meteoric origin) which usually have neutral or alkalic reaction and may thus become diluted. The general effect of these interactions is to increase the ph-value.

Thus the ph-value of thermal waters can be considered a measure of the degree of contamination. The more contaminated or diluted the magmatic gases the higher the ph-value of the thermal water. It is around 4 for the comparatively pure magmatic waters and attains 9 or 10 for the boiling or lukewarm « alkaline » hot springs. Thus we obtain another general relation : the farther the distance from the mother magma to the place of eruption of the spring the higher the ph-value.

An example of this regular increase of the ph-values with the distance from a magmatic centre is given in Fig. 2.

IV

I am well aware of the fact that several specific reactions affecting rock magmas or thermal waters will upset the relations presented above. Nevertheless these relations

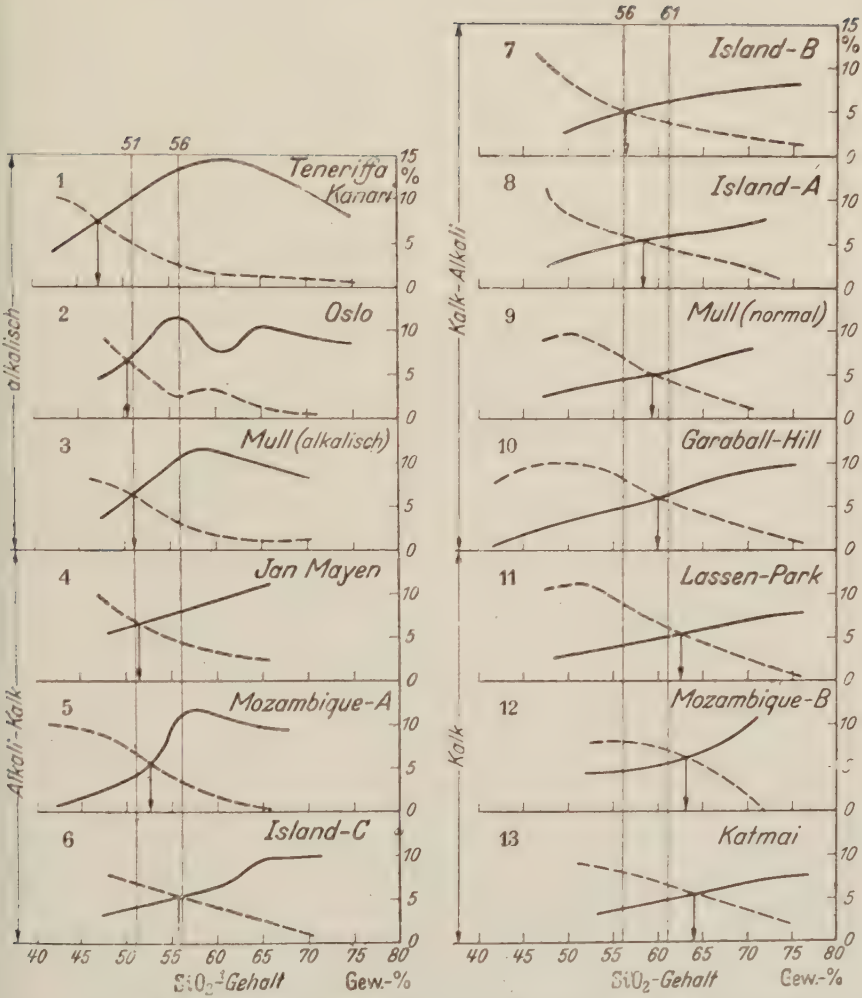


Fig. 1. – Variation diagrams for $Na_2O + K_2O$ (full lines) and for CaO (stippled lines) of 13 well-known rock series. The diagram shows the regular increase of the alkali - lime index as one passes from alkaline rock series to sub-alkaline rock series.

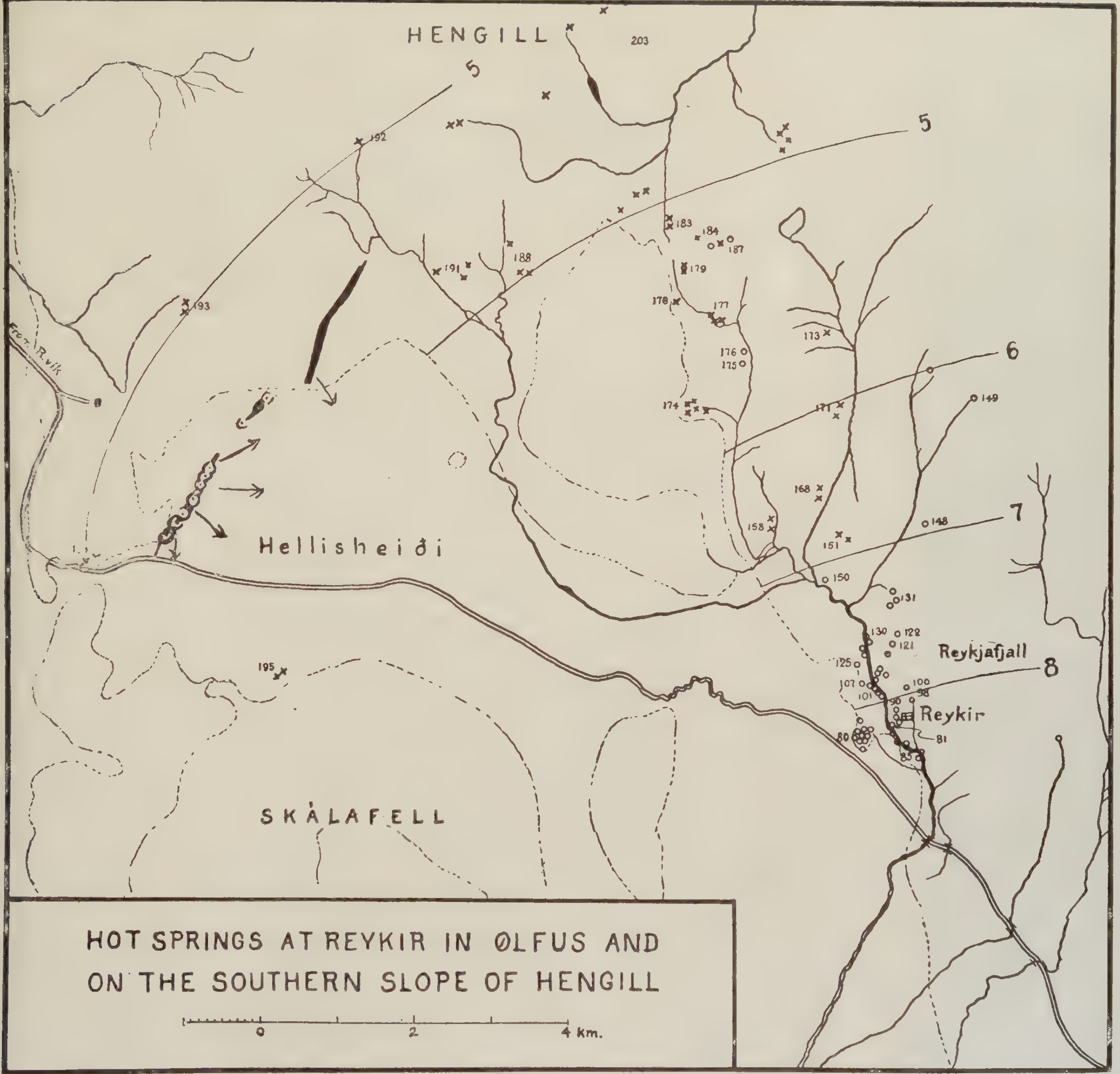


Fig. 2.— Map of a volcanic area in S. W. Iceland demonstrating the regular increase in the ph-value of hot springs with increasing distance from the loci of volcanic activity. The active line is here the axis Hellisheidi-Hengill where historic lava flows have issued from fissures and crater rows as shown on the map (stippled lines represent boundaries of the individual lava flows). Along this axis the magma is apparently still close to the surface; earthquakes are common and frequently cause new faults to develop in the surface. The emanations that reach the surface as thermal springs in the immediate neighborhood of this axis are very acid (ph below 5). Thermal springs farther away from the axis show higher ph-values; indeed, the increase in the ph-value is so regularly induced that it can be shown graphically on the map by regular lines. At Reykir, about 10 km from the active axis, the value has reached 8, and attains even 9 in some of the springs.

are statistically true. As a first approximation one can say, therefore, that the alkali-lime index and the ph-value, each within its own field, indicate the degree of contamination to which rock magmas or thermal waters respectively have been subjected.

Mineralogisk Institutt, Oslo.
June, 1939.

S. I. TOMKEIEFF

The basalt lavas of the Giant's Causeway district of Northern Ireland

(With 6 text-figures and 3 plates)

CONTENTS

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III. The petrography and the chemistry of the lavas . » 105
IV. The mode of formation of the lavas and of their structural features . . . . » 113
V. Summary . . . . » 135

I. — The history of investigation

« This mighty large Pile of Stony Columns that goes under the Name of the *Giants Causeway*, I take not only to be as Remarkable a Natural Curiosity of its sort as this *Country* affords, but perhaps as may be met with in *Europe* : For I cannot well imagine, that if a Fossil so extraordinary in its kind were to be found in any of these more civilized Parts of the World, that it could hitherto escape the many *Inquisitive Naturalists*, that of late by their Industrious Researches and Writings have so plentifully embellish'd, and so far advanced the *History of Nature* in all its parts. » (4, pp. 175-6). Thus wrote Molyneux in the year 1694, a year after the first scientific paper on the Giant's Causeway appeared in the transactions of the Royal Society of London. Giant's Causeway was no doubt well known to the natives of its district and probably to many other people in Ireland, but strangely enough the scientific 'discovery' of it was made by a person who had never seen it, by Sir Richard Bulkeley (1). This may explain why Bulkeley speaks of the Causeway as being composed of vertical 'cylinders' all of a solid piece, without any joints. To this a rejoinder by the Rev. Sam Foley soon followed in the form of two papers in which he corrected Bulkeley's description and gave quite a good description of the shape and jointing of the columns composing the Causeway (2,3). The first of these papers was provided with an engraving by C. Cole of a perspective view of the Causeway and a map. But it was Doctor Thomas Molyneux who took a real interest in the Causeway (4,6), although curiously enough he had not seen it either. He was the first to describe the characteristic ball-and-socket jointing of the columns and also the first to inquire into the nature of the rock out of which the Causeway is made. After discarding the alleged comparisons with crinoids, asteroids, and bamboo-stems, Molyneux quite correctly identified the rock as *Lapis Basaltes* of the variety *Basanos maximus Hibernicus*, or in modern parlance basalt. Strange as it may seem, this petrographical discovery, made in the year 1694, remains the most important contribution to our knowledge of this rock as, apart from some chemical analyses and certain passing references, petrological descriptions of the rocks of this district do not exist.

Molyneux was also responsible for sending a 'painter of some eminence' — Edward Sandys — to the Giant's Causeway with the result that 'a true prospect of the Giant's Causeway' was printed in 1697 (5). This 'true prospect' is really a work of imagination, for the coastal landscape is transformed deyond recognition, the rows of basaltic columns became luxuriant copses with leafy foliage replacing the upper part of the lava flows, ivy and shrubs are all over the place, and the picturesque crags to the east of the Causeway commonly called 'the chimneys' are metamorphosed into real smoking chimneys capping a cottage perched on an inaccessible cliff. So ends the first period of investigation of the Giant's Causeway.

The second period of investigation is foreshadowed by the publication in 1740 of two fine engravings of the Causeway from the paintings of Mrs. Susannah Drury.

These engravings had a wide circulation all over Europe and several continental geologists drew comparisons between the Giant' s Causeway as depicted on them and other similar localities on the continent.

The second period was actually inaugurated by the publication of a paper by the Rev. Richard Pococke (later Lord Bishop of Ossory) in 1748 (7), followed by two more papers (8, 9). By this time we are already hearing the distant thunder of the approaching storm the first tremors of the tremendous battle between the Neptunists and the Vulcanists, which lasted almost a century. This battle 'of the rocks' overshadowed the second period of investigation of the Giant' s Causeway, but the Causeway itself with its impressive structure played a certain part in the conflict.

Pococke was a Neptunist - he believed that the successive tiers of basaltic columns (he was the first to take a notice of the tiers of columns) were formed by precipitation from an aqueous medium. This was a long time before Werner, and in this connection it is important to realise that Werner was not, as it is sometimes believed, the creator of the Neptunist theory. The idea that all rocks were formed from an aqueous suspension or solution was the dominant petrogenetic theory prior to the middle of the eighteenth century. Volcanoes were considered as somewhat abnormal and a rare phenomena, and lava was explained as being due to the fusion of some other rocks by the heat developed by the combustion of sulphur or underground coalseams. The first move towards the establishment of the Vulcanist theory was made by Guettard, who was one of the first to point out that certain mountains, like those in Auvergne, are actually remains of ancient volcanoes (11). Apparently the same discovery was made almost simultaneously by Arduino in regard to the Euganean Hills in Northern Italy. It is very strange that Guettard, who made such an important discovery, never accepted the igneous origin of basalt. For him the terms lava and basalt were not synonymous. It was Desmarest who really started the battle about the origin of basalt. During his travels in Auvergne in 1763, Desmarest became aware that some of the lavas from well preserved craters are composed of columnar basalt. In his memoir published in 1771 (14) he actually proposed a new term 'basalt-lava', a term which to the majority of the scientists of that time sounded not only ridiculous but even revolutionary.

Desmarest was also responsible for the second important discovery relating to the Giant's Causeway. Although he had never been in Ireland and was judging solely from Mrs. Drury's drawing, Desmarest came to the conclusion that the columnar basalt of the Causeway was a lava. This is what he wrote on this subject : « ... cette consequence me fit voir, dans la Chaussée des Géans dans toutes les masses prismatiques qui se montrent sur les bords escarpés de la mer en Irlande, en un mot, dans les sommets tronqués qu'on y aperçoit, l' ouvrage des éruptions d' un ou de plusieurs volcans qui se sont éteints comme ceux d'Auvergne ». (14, p. 709).

A learned Hanoverian, R. E. Raspe, did not hesitate long in accepting Desmarest's theory of the origin of basalt and he applied it to certain basalts from Hesse (15). He later expounded it in a book published in 1776 under an expressive title (19). This is what Raspe wrote in this book about the Giant's Causeway :

« The Irish basalts in the Giants-causeway in the county of Antrim appear in polygon articulate columns or prisms. There ought to be some natural reason for that, whatever it be. Is it owing to the difference of their substance and mixture ? to the different sloping of the ground on which these fiery melted masses run forward ? to the different quickness of their motion ? to their different fluidity or is it owing rather to the manner of their refrigeration ? » (19, p. 48). And here is his own answer to his query : « The regular prismatic columnar black rock or basalt seem, according to their situation and quality in this country, and in many others, to be lavas, which in a hot-fluid state broke their way from underground immediately in the sea, or ran into it, or cooled under its level, without any eruption, within the strata, caverns, and holes, wherein they have been brought to fusion. » (19, p. 54). The meaning of this slightly obscure passage is that the columnar nature of basalt lava is due to the rapid chilling of the fluid lava as it ran out into the sea.

At the time when this was written many other columnar basalts resembling the basalt of Stolpen described by AGRICOLA and that of the Giant's Causeway were known. Here is a brief chronological list of these discoveries. In 1756 TREMBLY had discovered columnar basalts in western Germany which he compared to those of the Giant's Causeway (10). In 1762 POCOCKE (Lord BISHOP OF OSSORY) found similar rocks at Dunbar, Scotland (12) and MENDEZ da COSTA in Canna, Inner Hebrides (13). As described by Thomas PENNANT (16), Sir Joseph BANKS discovered the famous Fingal's Cave in Staffa in 1772. In 1775 STRANGE, the British ambassador at Venice, described some columnar igneous rocks of the Euganean Hills (17, 18). At a later date MILLS described the basaltic rocks of Ireland and Inner Hebrides (26).

The gathering forces of the Vulcanists were reinforced by the remarkable work of FAUJAS DE SAINT FOND, an intrepid champion of this cause, a great traveller and a prolific writer. FAUJAS was the first geologist to visit Staffa and he gave a geological description of this classical island in 1784. It was left to HAMILTON and WHITEHURST, however, to investigate Giant's Causeway and to study it for the first time from a new point of view. The Reverend William HAMILTON (not to be confused with Sir William HAMILTON, the British ambassador at the Court of Naples and also a famous volcanologist), visited Giant's Causeway and other parts of Antrim in 1784 and in 1786 he published his observations in the form of beautifully written letters (21), later republished in book form (25). Unlike previous observers, HAMILTON did not limit his observations to the Causeway itself but extended them to the adjoining cliffs with their magnificent tiers of columnar ranges, and to other parts of Antrim including Rathlin Island. HAMILTON definitely identified basalt with lava and most vigorously defended the volcanic theory against its opponents « many of them plainly tending to multiply false opinions, and to subvert the only true principles of religion and morality » (21, p. 173). Besides a very interesting description of the rocks of Antrim, HAMILTON gave the first measured vertical section of the lavas. He was followed by WHITEHURST, who, after publishing the first edition of his famous book, visited Antrim in 1786 and incorporated in the second edition of this book (22) observations that he made there. WHITEHURST, like HAMILTON, accepted the volcanic origin of basalt and in addition suggested that in Antrim there must be a number of lava flows erupted from a crater probably situated to the north and at the present time submerged below the level of the ocean. The appearence of the works of HAMILTON and WHITEHURST was rather opportune, for in 1785 James HUTTON read before the Royal Society of Edinburgh his famous paper on the theory of the earth. This work was published in 1788 (23) and subsequently a revised edition was published in book form (28). The publication of HUTTON's 'Theory' stirred up the camp of the Neptunists, and HUTTON was bitterly attacked first by KIRWAN (27) and then by others. In this way the battle about basalt which had started on the Continent some 20 years before, extended to the British Isles. The principal battlefields were situated at Edinburgh, Glen Tilt, Portrush, and Giant's Causeway. The last locality became the stronghold of a bitter opponent of HUTTON, the Rev. W. RICHARDSON (29, 30, 31, 33, 35, 36). Like many other writers of the period, RICHARDSON appealed to the principles of religion and morality, and this, for example, is his opinion of DESMAREST: «...this associate of VOLTAIRE and D'ALEMBEBT, in their labours to rid mankind of their religious prejudices, this same M. DESMAREST is now stiled the father of the volcanic theory, having, in the course of the mission upon which we have traced him, discovered basalt to be a volcanic production : nor did he neglect to apply his discovery to the main object of his mission, to wit, an impeachment on the credibility of Moses... » (31, p. 439).

But in spite of his vituperations against the accursed vulcanists and in spite of his many absurd arguments in defence of the aqueous origin of basalt, Richardson made a great number of true and very valuable observations. He was the first to give a good description of basalt dykes in Antrim, to note the two-fold division of the basalt lava flows, which he later named the upper irregular prismatic and the lower regular columnar. He also gave the most accurate measured vertical section of the lavas that has ever been given before or since.

This outburst of Neptunism was the last spasm of a dying theory. The work of Conybear and Buckland on the geology of Antrim, published in 1816 (39), does not show any traces of this controversy and apparently the volcanic theory was taken by them for granted. This work, by the way, is accompanied by a very fine section of the Antrim coast. The work of Conybear and Buckland may be said to open the third and last period in the study of the Causeway. On the whole, this period as compared with the preceeding period of ‘ Sturm und Drang ’ is dull and uninspiring, and adds very little to the knowledge of the nature and the structure of the Giant's Causeway. Some of the works belonging to this period will be discussed later.

II. - The structure of the lavas

When the visitor has finished admiring the Causeway and turns to look at the magnificent cliffs situated to the east of it, he cannot escape noticing the remarkable tier arrangement of the columnar ranges of lavas intercepted by, what looks at a distance, more massive bands (Pl. I, Fig. 1). This two - fold arrangement of lava-flows is frequently found and since the time of Desmarest it has often been described and reproduced in illustrations.

In this type of flow one can distinguish the following zones :

a) upper zone composed of closely spaced wavy columns or of thick vertical columns (pseudo-columnar jointing), or both. The uppermost part of this zone is usually vesicular and slaggy.

b) lower zone composed of regular vertical columns.

To simplify description I should like to propose the terms *entablature* and *colonnade* for the upper and lower zones respectively. These terms have been borrowed from classical architecture and they apply quite well to this type of lava which, in vertical section, has a certain resemblance to a classical temple. In spite of his Neptunist views RICHARDSON gave a very good description of this type of lava. « It is composed of two strata, the lower columnar, the upper of that variety of basalt I have called irregular prismatic. The grain of the basalt in each stratum is precisely the same, the principle of their construction totally different ; the columnar formed into large articulated pillars, always nearly vertical, the other into prisms much smaller, not articulated, and with their axes indifferent to all position, and perpetually changing them. Notwithstanding these important differences, these strata here, and everywhere else, pass into each other *per saltum* and never *per gradus*, leaving the line of demarcation, between them (at least when viewed from some little distance) tolerably correct and, in the transit from one stratum to the other, the solidity or continuity of the material is never interrupted, as appears by cracks passing from one stratum far into the other ». (38, pp. 57-8).

Besides being called ‘ irregular prismatic ’ this zone or the rock of this zone have been called ‘ starchy ’ ‘ amorphous basalt ’, close-spaced wavy columns ’, ‘ irregular columns ’, ‘ confused columns ’, and several other terms. The term entablature, however, does not specify the structure of this part of the lava flow, it merely refers to its position as being above the colonnade, and in this way any possible ambiguity is avoided.

It is really remarkable how this structure of the lavas was misinterpreted by so many writers and illustrators. The most famous blunder was made by SANDYS who, as already mentioned, produced in 1697 the famous 'true prospect' of the Giant's Causeway (5). In this engraving the colonnade is transformed into a row of tree trunks and the entablature into their foliage. RICHARDSON at one time (36) considered the entablature and the colonnade to be distinct strata, while other observers thought them to be distinct lava flows. On the other hand ROHLEDER (81,86) made one single flow out of a colonnade and entablature of one flow and a colonnade of the flow above, thus postulating a flow with two colonnades symmetrically disposed about the entablature.

The basalt lavas of Antrim can be divided into two sets : the upper and the lower lavas. These two sets are separated by the major interbasaltic zone composed of laterite, bauxite, lithomarge or bole. In the northern part of Antrim these two sets of lavas consist of different kinds of basalt. The upper lavas are composed of compact, fine-grained tholeiitic basalt, which is well jointed and the flows of which are usually divided into a colonnade and an entablature, and are relatively thick. The lower lavas are composed of a coarse olivine-basalt or rather dolerite and in their upper and sometimes lower part are highly vesicular and zeolitic. These lavas are relatively thin and have a block or spheroidal jointing, but occasionally pseudo-columnar jointing is also developed. Each flow as a rule has a reddened upper surface, which when fully developed is composed of bole or laterite (interbasaltic zone).

These two sets of lavas are magnificently exposed in the cliffs adjoining the Causeway. This region represents a fault-block separated from the lavas to the south by a powerful fault approximately running W-E, from the mouth of the river Bush to Portbraddan in White Park Bay. The lavas are gently dipping to the SSE. The base of the lavas is nowhere exposed north of the fault, but immediately south of the fault near the river Bush the lower lavas can be seen resting on the Clay-with-flints, overlying Chalk. The thickness of the lower lavas in this locality can be estimated at 200 feet. Towards the east the lower lavas thin out rapidly — in the White Park Bay they are not more than 50 feet thick, and farther east near Carrick-a-Raide, their thickness is even smaller. Between Plaiskin Head and Bengore Head the thickness of the lower lavas exposed in the cliff section is not less than 160 feet and therefore no more than 40 feet of lavas could be expected to be found below the level of the ocean. The exposed lavas comprise 7 or 8 flows so that the total number of flows cannot be more than 11. The flows often thin out completely. Their maximum thickness is 30 feet and their average thickness probably about 20 feet. The thickness of the red partings varies from 1 to 5 feet. The major interbasaltic zone is 20-30 feet thick, and quite possibly it represents a single completely altered lava flow — the uppermost flow of the lower set. Even if we include this major interbasaltic zone among the lower lavas, their total thickness in this region cannot exceed 225 feet in average.

Of the upper lavas only two lower flows and the lower part of the third flow are exposed near the Causeway, but following the coast from Bengore Head to Port Moon and Dunseverick one can see in the cliffs the complete third flow and the lower part of the fourth flow. The upper lavas are separated from each other by very thin lateritic zones, only in pockets reaching the thickness of ten feet. In the cliffs these lateritic bands form grassy ledges. In some places detrital laterite and lignite have been found.

The following table gives the average thicknesses of lavas in feet (the red interbasaltic zones, with the exception of the major zone, are included in the lavas).

Table I

The average thicknesses of lavas in feet

Upper Lavas	4th flow	Entablature	?			
		Colonnade	60			
				60		
	3rd flow	Entablature	52			
		Colonnade	8			
				60		
	2nd flow	Entablature	25			
		Colonnade	50			
				75		
	1st flow	Entablature	55			
		Colonnade	45			
				100		
					295	
Lower Lavas	Major interbasaltic zone			25		
	Lavas exposed			160		
	Lavas covered			40		
					225	
			Total			520

A diagrammatic vertical section of the lavas is also given in Fig. 1. In this section an attempt has been made to represent the various structural types observed in these lavas. This section should be compared with some of the photographs and engravings especially with Pl. I, Fig. 1. But photographs of separate occurences do not show the variation of lavas structure in a horizontal direction. For example in the first (lowest) flow of the upper lavas the colonnade is frequently reduced in size or even disappears altogether, and the curvi-columnar zone of the entablature

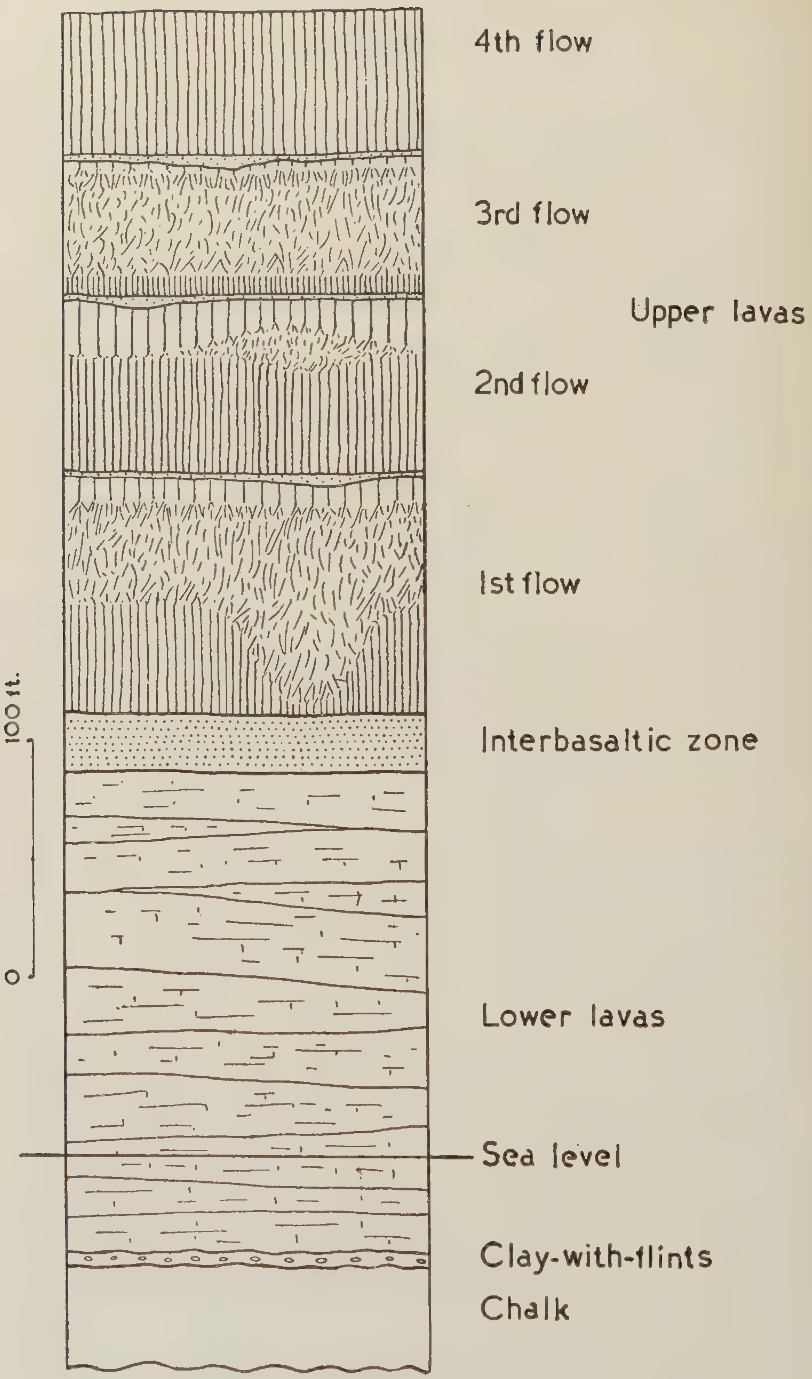

Fig. 1. — Diagramatic vertical section of the lavas as exposed in the cliffs adjoining Giant's Causeway. The entablature of the 4th flow is probably removed by denudation. The interbasaltic zones of the upper lavas and the major interbasaltic zone are shown by stippling. The interbasaltic zones of the lower lavas are omitted.

begins almost at the base of the flow. On the other hand in the second flow the curvi-columnar zone is poorly developed and often absent altogether. In the third flow it is the colonnade that is very thin and the curvi-columnar zone of the entablature that is thick.

The columns of the colonnade are on the average 2 feet in diameter. The columns of the curvi-columnar zone are much thinner, never more than one foot and usually less. The pseudo-columnar joint-blocks of the upper part of the entablature are very thick — on an average four feet in diameter. The columns of the colonnade are divided by cross joints into separate blocks. The cross joints do not pass from one column to another but are rigidly restricted to each individual column. The distance between them varies from ½ to 2 feet, being on an averange ¾ feet. The majority of these joints are of the so-called ball-and-socket variety. They are orientated upwards and downwards in a most irregular manner.

The entablature presents a great variety of structural features. In a well developed entablature the structural elements are as follows :

1. Slaggy (vesicular) upper zone, which is usually very thin and often composed of altered rock.

2. Pseudo-columnar zone composed of rude, thick and short joint blocks, sometimes resembling real columns.

3. Curvi-columnar zone composed of curving thin columns often radiating from certain points situated along the upper and the lower margins of this zone. The lower margin bordering the colonnade is usually well defined, but the rock itself is perfectly continuous across the margin.

The structure of the lavas as described is clearly seen in the beautiful photograph by R. Welch (Pl. I, Fig. 1) and the ball-and-socket jointing on the photograph of the Giant's Causeway (Pl. I, Fig. 2). In way of comparison two 18th century engravings are given (Pl. II, Fig. 1-2). They are dated 1776 but they are to be found along with other engravings of columnar lavas and other geological objects in a volume published in 1825 (41). In Fig. 1 the three upper lavas are represented, but the delineation of the entablature is rather crude. Fig. 2 represents « The Giant's Loom » situated on the eastern side of the Causeway, and the ball-and-socket jointing is clearly seen.

The colonnade is made of vertical or slightly curving columns closely packed together in the form of polygonal prisms. The horizontal plan of the colonnade, so magnificently displayed in the Causeway, shows, a complex network in which six-sided polygons predominate, but four-, five-, seven- and eight-sided polygons are also present (57, 58).

Several hypotheses have been advanced to explain columnar jointing in igneous rocks :

1. Crystallization hypothesis — widely held prior to the 19th century — according to which the columns represent crystals of certain minerals such as quartz or tourmaline. Some of the old engravings even represented basaltic columns with pyramidal terminations. This hypothesis was abandoned in the second half of the 18th century, although, strange to say, it was revived by O' Reilly in 1879 (57).

2. Contraction hypothesis, which explained the joints as being due to the contraction of the rock on cooling, was first suggested, so far as I am aware, by the ingenious author of Baron Münchausen, the versatile R. E. Raspe in 1776 (19). Raspe thought the subaqueous cooling of the lava was the cause of this jointing, but it was later shown that an ordinary subaerial cooling was sufficient. This hypothesis was accepted and developed by Scrope (40), Thomson (48, 53, 60) Mallet (55), Bonney (56), Iddings (63, 72), Lomas (67), and James (75), and at the present time probably most geologists would agree in accepting it as the only true explanation of this type of jointing.

3. Crystallization-concretional hypothesis, which is probably of historical interest only. It was suggested by Watt, who observed that molten basalt on crystallization tends to develop a spherulitic structure (32). This led him to the supposition that the columnar structure might be due to the packing up of the spherulites in a regular manner.

4. Convection hypothesis, developed by **Benard** and **Dausere**, according to whom convection currents in a cooling magma are responsible for the formation of columnar structure. A good account of this hypothesis may be found in the paper by **Sosman** (74). Actually, neither the structure of the lavas, nor their texture lend any support to this hypothesis.

The mechanism of jointing in igneous rocks was very ably treated by **Mallet** (55), who gave a very neat mathematical explanation of the formation of columnar joints. His theory of the formation of the ball-and-socket jointing cannot, however, withstand the field evidence. According to his theory the convexities of these joints should always face the same way in the columns, but this is certainly not the case. **Thomson**, who was the first to note the radial ribbings on the surface of ball-and-socket joints, suggested another explanation of them. According to him they are due to the expansion of the outer part of the columns and the consequent fracturing of the interior of the columns. On the other hand **Preston** (87) postulated contraction of the outer part of the column and suggested that the fissure started at the outside of the column and then rapidly penetrated into the inner part. The curvature of the joint plane is explained by him as being due to the unequal cooling of the column in the vertical direction. Like the theory of **Mallet** this theory would work if the concavities of the joints were facing the same way. Unfortunately they do not.

The difference between the joint-systems of the entablature and the colonnade has been attributed to the different rate of cooling of a lava flow from the top and from the bottom respectively. **Iddings**, following previously expressed opinion, wrote : « the more rapid the cooling in any given rock, the closer together will be the cracks due to shrinkage » (72, p. 321), and he suggested, therefore, that the upper part of a lava flow where the columns are thinner, cools more rapidly than the lower. Although it may be true that the top of the lava flow cools more radly than the bottom, but it is not true to say that the joints in the upper part of the flow are always more closely spaced than those of the bottom of the flow. A fully developed joint structure, like that of the lowest flow of the upper lavas of the Causeway region (Fig. 1), shows that the joints of the upper part of the flow are more widely spaced than the joints of the lower part. The most closely spaced joints, however, are found in the middle part of the flow, where the cooling could not have been very rapid. This disqualifies Iddings explanation.

An attempt to solve the various problems of the jointing will be made in the last part of the paper.

In conclusion mention must be made of the red interbasaltic zones and of the dykes. It was Faujas de St. Fond (20, pp. 196-9) who was the first to discover the gradual passage from fresh basalt to the red interbasaltic material and suggested that the latter is merely an altered basalt. Richardson also wrote that « this stone is merely basalt in a certain state of decomposition (33, p. 20). In spite of these correct interpretations of the origin of the red rock, many fantastic opinions were produced. Hamilton, for example, thought that the red colour of this rock is due to « the powerful action of heat » (21, pp. 146-7), Griffith believed that this rock was formed from volcanic ashes thrown out by submarine volcanoes (42), an opinion shared also by Kelly (51) and by the authors of the Geological Survey Memoir (65). The true nature of this rock was revindicated by Tate & Holden (52) and finally established by Cole and his co-workers (70, 73). But it must also be noted that besides the residual products of weathering, there are also detrital products, including laterite, iron ores, and lignite. Volcanic ashes are also present in Antrim, but these cannot be confused with laterite. Interbasaltic red zones composed of laterite, bauxitic clay, lithomarge, and bole represent the products of weathering of basaltic lavas and were probably formed under sub-aerial and tropical climatic conditions.

The dykes in this region are all, without exception, composed of olivine—basalt and olivine—dolerite, identical with those forming the lower lavas. They cut right through the lower and the upper lavas and thus belong to a later stage of igneous activity.

III. — **The petrography and the chemistry of the lavas**

A) - Petrography

Apart from two short notes, one by Lacroix (62) and the other by Hatch (in 65), there is no petrographical description of the basalts of the Giant's Causeway district. These basalts fall into two distinctive types. The contrast between the upper and the lower lavas is very striking, the first being composed of a fine-grained compact basalt with a sub-conchoidal fracture, the second being a rather coarse olivine — basalt or even olivine — dolerite.

As their texture, and in particular their granularity, is such an important diagnostic character, it may be well to examine here methods of ascertaining it in given rocks before proceding to use it as a factor in the study of the rocks and the formation of the lavas.

A simple quantitative estimation of granularity can easily be combined with the modal analysis of a rock on a recording stage. This method consists of counting the number of grains of each mineral measured. Then by dividing the total traverse per mineral (t) by the number of grains (n) one can get the average linear intercept of a given mineral (1). The average linear intercept of a given rock (L) can be calculated by means of the following formula, in which p is the volume percentage of a given mineral.

$$L = \frac{l_1 p_1 + l_2 p_2 + \ldots + l_m p_m}{p_1 + p_2 + \ldots + p_m}$$

This method is obviously only applicable for grains not smaller than 0.001 mm. and this means that all the fine-grained, microlitic, fibrous, and glassy components of rocks are being ignored.

The average linear intercepts, even when obtained, do not express the real grain-size of a rock, but as they are probably more or less proportional to it, they can, on the whole, be taken as indices of the granularity of various rocks for the purpose of their comparison. It is for this reason that the values of the average linear intercepts have been inserted in Tables II and III together with the modal analyses.

The lower lavas. — The absence of new quarry exposures made it difficult to obtain fresh samples of the lower lavas. The presence of zeolitic material and spheroidal jointing make this rock an easy target for weathering. Two samples taken from the same flow have been measured on the Shand' s recording stage (Table II). The difference in

TABLE II

Modal composition of lower lavas (volume %%)

	1	2	Average (volume)	Average (weight)	3 (weight)
Olivine (Serpentine)	15.30	14.20	14.75	13.45	18.55
Feldspar	41.65	32.60	37.10	34.65	34.80
Pyroxene	25.10	29.70	27.40	29.90	32.50
Iron Ore	5.05	6.40	5.75	8.30	4.90
Mesostasis	12.90	17.10	15.00	13.70	9.25

Granularity (in mm.)

	1	2
Olivine	0.236	0.219
Feldspar	0.057	0.033
Pyroxene	0.395	0.540
Iron Ore	0.023	0.005
L.	0.186	0.245
Sp. Gr.	2.821	2.817

1. Olivine-dolerite. Near the bottom. Flow immediately below the major interbasaltic zone.
2. » » Central part. Same flow.
3. » » Central part of a lava flow. Island Magee Co. Antrim (91).

composition of the two samples is very small and there is no evidence of the gravitational enrichment in olivine in the lower part of the flow, as it is the case in some flows (91). If the value of the average linear intercept (L) separating basalt from dolerite is taken as being 0.100 mm., then the two samples must be classed as dolerites. Even without such quantitative criterion the rocks in question can safely be classed as ophitic olivine-dolerites. On the whole these rocks do not differ much from any other olivine dolerite lavas of Antrim. For comparison a modal analysis of a lava from Island Magee is given, but it must be remembered that this particular lava does show an effect of gravitational separation of olivine.

The constituent minerals of these lavas are olivine, feldspar, pyroxene, iron ore, chlorite, and zeolite. The olivine is almost completely altered to serpentine, iddingsite, chlorite, and iron ore. The phenocrysts of olivine are comparatively small and occasionally enclose plagioglase laths. The last feature is common to all Irish Tertiary dolerites and basalts. The composition of olivine, as determined from similar rocks of other localities, averages Fa_{25} Fo_{75} but usually it is zoned with a variation from Fa_0 Fo_{100} to Fa_{45} Fo_{55} (96). The felspar laths have a maximum extinction of 30° in albite twin lamellas and are therefore labradorite. Zonal structure with alkaline margins is fairly common. The pyroxene is a purplish-brown augite occurring in the form of large ophitic plates. It is often chloritized. The iron ore occurs in the form of small idiomorphic grains. It is often moulded on the feldspar laths. The mesostasis consists of a micro-fibrous green chlorite and zeolite (mainly chabazite). Slender apatite needles are abundant.

The upper lavas. — The upper lavas are wery uniform in composition and grain-size. Except for the few inches of marginal chilled facies, the rock right through the whole thickness of the flow is more or less uniform in composition and grain-size, a fact that can be easily seen from the modal analyses and grain-size determination (Table III).

TABLE III

Modal composition of the upper lavas (volume %%)

	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.
Feldspar .	36.10	35.10	33.60	50.00	29.30	37.10	38.90	36.40	35.20	32.00
Pyroxene .	41.70	44.60	36.30	22.00	44.20	48.40	42.50	41.75	42.75	46.30
Iron Ore .	3.40	4.50	1.10	4.00	5.15	4.25	5.35	1.60	3.65	5.25
Mesostasis .	18.80	15.80	29.00	18.00	21.35	10.25	13.25	20.25	18.40	16.45

Granularity

Feldspar .	0.027	0.036	0.030	0.026	0.030	0.026	0.040	0.037
Pyroxene .	0.035	0.038	0.035	0.007	0.035	0.020	0.035	0.035
Iron Ore .	0.001	0.001	0.001	0.009	0.001	0.003	0.002	0.002
L	0.030	0.035	0.032	0.017	0.031	0.022	0.035	0.035
Sp. Gr. . .	2.909	2.892	2 888	2.823	2.841	2.814	2.861	2.882

THOLEIITIC BASALTS

1. Lower part of the colonnade. Giant's Causeway. 1st flow.
2. Upper part of the colonnade. Path leading to the Causeway. 1st flow.
3. Lower part of the entablature, 1 ½ feet above no. 2, same locality.
4. Upper slaggy zone. Above the Organ. 1st flow.
5. Colonnade. Port Reostan (The Amphitheatre). 2nd flow.
6. Lower part of the entablature. Port na Spania. 2nd flow.
7. Upper part of the entablature. Port Reostan. 2nd flow.
8. Colonnade. Port Reostan. 3rd flow.
9. Average of nos 1, 2, 3, 5, 6, 7 and 8 (volume %%).
10. Same (weight %%).

The rock is a fine-grained tholeiitic basalt. A small amount of olivine was probably present during the early stages of crystallisation, but in its present condition only small patches of serpentine, sometimes preserving an outline of idiomorphic crystals of olivine, are the only indications of a former presence of this mineral. The amount of this material is too small and its nature too indefinite to be included in the modal analysis. The most abundant mineral is a brownish-green augite which invariably occurs in the form of minute stumpy idiomorphic crystals. Only very occasionally does it become subophitic towards plagioclase. Clusters of augite crystals together with grains of iron ore are found in the meshes between the network of plagioclase laths and the later mineral is moulded on augite. The plagioclase is in the form of slender laths. It is fresh and twinned according to the albite law with a maximum extinction angle of 25° and corresponds therefore to a basic andesine. Orientated sections taken from different parts of the basaltic columns failed to show any indication of fluidal orientation of the plagioclase laths. The iron ore is in the form of minute grains, but dusty and skeletal aggregates of ore are found in the glassy mesostasis. The mesostasis is very conspicuous and abundant. It is disposed in patches and streaks and thus the name of tholeiitic basalt is justified. Its composition, which can be estimated only roughly, is as follows: brownish glass (refractive index below C. B) -30 %, iron ore and some other minerals -20 %, chloritic material -50 %. The greater part of chloritic material in the mesostasis is palagonite, but isotropic chlorophaeite is also found. The last mineral is more abundant in vesicles. In opal-infilled vesicles celadonite lines the walls. Zeolite-infilled vesicles occur only in the upper part of the entablature.

B) - Chemistry

The lower lavas of the Causeway district have never been analysed. But as they are similar to other olivine-dolerite lavas of Antrim an analysis of the lava from Island Magee is given here for comparison with the analyses of the upper lavas (Table IV).

Table IV

Chemical composition of the lavas

	1.	2.	3.	4.	5.	6.	7.	8.
SiO_2	46.12	46	52.13	51.20	50.36	50.71	50.89	35.995
TiO_2	1.37	—	—	0.96	1.06	0.99	1.12	—
Al_2O_3	15.46	16	14.87	14.60	14.51	14.66	14.52	10.485
Fe_2O_3	3.85	22	—	4.56	2.61	2.39	2.21	11.890
Cr_2O_3	—	—	—	—	0.02	—	—	—
V_2O_3	—	—	—	—	0.04	—	—	—
FeO	6.51	—	11.40	8.13	8.09	8.19	8.81	1.626
MnO	0.21	—	0.32	—	0.12	0.22	0.10	0.077
MgO	10.12	3	6.46	4.40	6.26	5.91	4.07	10.517
BaO	—	—	—	—	0.03	—	—	—
CaO	10.66	10	10.56	10.35	10.77	10.53	9.11	5.15
SrO	—	—	—	—	0.05	—	—	—
Na_2O	1.48	—	2.60	3.23	2.48	2.63	3.13	0.761
K_2O	0.65	—	0.69	0.82	0.99	0.89	1.01	0.338
P_2O_5	0.06	—	—	—	0.45	0.50	0.62	—
S	—	—	—	—	0.06	0.04	0.10	—
CO_2	—	—	—	0.04	0.10	0.06	0.17	—
H_2O +	2.38	—	1.19	2.11	1.10	1.22	2.84	9.047
H_2O —	1.01	—		—	1.27	0.94	1.22	14.156
	99.88	97	100.22	100.40	100.37	99.88	99.92	100.997

The upper lavas were more fortunate in this respect. The first analysis of the Giant's Causeway basalt was published by Faujas de Saint Fond in 1788 and it was probably the first analysis of any Irish rock ever published. This analysis is given in Table IV merely as an historical curiosity. The second analysis by Streng is much more accurate, but it is still not up to modern standards. The best analysis of the Giant's Causeway basalt is that published by Holmes (Table IV, no. 5).

TABLE V

NIGGLI values

	1.	4.	5.	6.	7.	8.
si.	100.0	127.8	121.8	124.7	137.2	92.8
qz	-16.0	-8.6	-7.4	-6.1	-2.8	-17.2
al	19.5	21.4	20.7	21.2	22.9	16.0
fm	51.5	41.8	44.0	43.3	40.8	67.2
c	25.0	27.7	28.0	27.7	26.3	14.3
alk	4.0	9.1	7.3	7.7	10.0	2.5
mg	0.64	0.39	0.51	0.50	0.40	0.60
k	0.23	0.17	0.21	0.18	0.17	0.25
ti	2.22	1.80	1.93	1.83	2.27	—
p	0.05	—	0.47	0.52	0.71	—
h2o	24.60	17.50	19.10	17.70	36.40	82.20

1. Olivine-dolerite. Central part of a lava flow. Island Magee, Co. Antrim. Anal. S. I. TOMKEIEFF, 1934 (91).
2. Tholeiitic basalt. Giant's Causeway. Anal. B. FAUJAS DE SAINT FOND, 1788 (24).
3. » » Giant's Causeway. Anal. A. STRENG, 1853 (44).
4. » » Giant's Causeway. Anal. T. V. M. RAO, 1928 (83).
5. » » Giant's Causeway. Anal. Messrs. Imperial Chemical Industries Ltd., 1936 (92).
6. » » Colonnade of the 2nd flow, Port na Spaniagh, 3/4 miles NE of the Giant's Causeway. Anal. S. I. TOMKEIEFF (new analysis).
7. » » Entablature of the 2nd flow. Port na Spaniagh. Anal. S. I. TOMKEIEFF (new analysis).
8. « Aluminous Chlórophaeite », from basalt, E. of the Giant's Causeway, Anal. M. F. HEDDLE, 1880 (59).

In order to see whether there is any difference in composition between the entablature and the colonnade, two samples of basalt from these two zone were analysed. Both samples were taken from the second flow. The first came from the lower part of the colonnade, and the second from the entablature about three feet above the colonnade. The entablature in this locality has a pseudo-columnar structure and is composed of a light-coloured variety of basalt rich in opal-infilled vesicles. The material selected for analysis was free from visible opal and chlorite infillings. These two analyses show that the difference in composition between the lower and the upper part of the flow is small. The rock of the upper part is slightly richer in alkalies and poorer in MgO and CaO, but the most important difference is in the content of water. The amount of water in the upper part is nearly twice of that of the lower part. A fair sample of the rock as a whole, which would include the abundant opal and chlorite vesicular infillings would, no doubt, show a far greater proportion of water. This suggests that a certain amount of differentiation did take place in the liquid lava. This differentiation probably consisted in the diffusion of a hydrous alkaline solution towards the upper part of the flow.

As already mentioned, the mesostasis of basalt consists of glass and chlorite. The chloritic material is an important constituent, as it forms about 10 % of the rock. The main portion of it consists of a greenish fibrous chlorite, which one may call palagonite. Palagonite is probably not a definite mineral, but a chloritized product of basaltic magma or, as suggested by M. A. Peacock, a hydrogel of sideromelane (basalt glass). Besides fibrous palagonite, isotropic chlorophaeite is also found, especially in vesicles. Heddle, who has analysed this material, called it an « aluminous chlorophaeite » (59). According to its chemical analysis and its Niggli values (Tables IV & V), this material can be as well interpreted as a hydrous magnesia-enriched fraction of the basaltic magma. The occurrence of chloritic material in form of streaks suggests that it had separated in a liquid state prior to the solidification of the magma. It may be that chlorite (palagonite and chlorophaeite), opal, and zeolite in their totality represent this hydrous complementary fraction of the magma.

The difference in the composition of the olivine-basalt (lower lava) and the tholeiitic basalt (upper lava) is well marked. The tholeiitic basalt is richer in SiO_2, FeO and alkalies, while the olivine basalt is richer in MgO, $Al_2 O_3$ and $Fe_2 O_3$. The differences in the chemical composition is reflected in the respective mineral composition of the respective rocks. In the tholeiitic basalt the feldspar, for examples, is more alkaline. The higher amount of MgO in the olivine-basalt explains the presence of olivine, although this is partly compensated by the higher amount of a more magnesian pyroxene in the tholeiitic basalt.

IV. — The mode of formation of the lavas and of their structural features

1. — The mode of origin of the lava-types

In their scheme of classification of British Tertiary igneous rocks, Bailey and Thomas have proposed the term ‘ magma-type ’, a concept based on chemical composition alone (77). Rocks of diverse structure and genesis (effusive, intrusive) are grouped together under one magma-type. The concept of a lava-type used in this paper is more restricted in its scope and refers solely to a type of effusive rock characterised by a definite mineralogical as well as by a definite chemical composition. Actually there are only two lava-types present in the district dealt with in this paper, and these are : the olivine-basalt (dolerite), corresponding to the plateau magma-type, and the tholeiitic basalt, corresponding to the nonporphyritic central magma-type. The difference between these two types can be clearly seen from the modal and chemical analyses (Tables II, III and IV).

KENNEDY's (88, p. 63) tabulation of the main petrographical characters of these types is as follows :

	Olivine-basalt (Hebridian Plateau Type)	Tholeiitic basalt (Nonporphyritic Central Type)
Olivine	Abundant, often occurs as microphenocrysts ; sometimes it is of late crystallization.	Subordinate or absent
Pyroxene	Purplish titan-augite. Seldom or never forms phenocrysts. Usually ophitic.	Colourless or light-brown enstatite-augite. Phenocrysts sometimes present. Usually granular.
Mesostasis	Alkaline - usually analcite or some related zeolite. No glass.	Glass.

The additional petrographical and chemical characters of the lavas of the Giant's Causeway district are as follows :

Feldspar	Labradorite. More abudant than pyroxene.	Andesine. Less abundant than pyroxene.
Mesostasis	Lime zeolite, chlorite.	Glass, palagonite, chlorophaeite.
Chemical characters.	Richer in MgO, CaO, TiO_2, Al_2O_3, Fe_2O_3.	Richer in SiO_2, FeO, Na_2O, K_2O, P_2O_5, H_2O.

The remarkable uniformity in composition of these two lava-types over the whole volcanic region of Scotland and Ireland, and the extreme rarity of transitional types, present great difficulties in the way of any theory of differentiation of these types from a common magma. In this connection it is also important to realise that the olivine-basalt lavas are the most abundant of the two. A rough estimation of the relative abundance of the lavas in Antrim is as follows :

Olivine-basalt lavas	80 %
Tholeiitic basalt lavas	15 %
Rhyolite lavas	5 %
	100 %

The relative abundance of the plateau magma-type was one of the reasons that prompted BAILEY and THOMAS to postulate it as the parental stock. The second reason for this was the possibility of arranging most of the Mull magmatic time-sequences into cycles, each beginning with the plateau magma-type (77, p. 30). To explain the magmatic time-sequences they tentatively suggested a process of differentiation controlled by crystallization and by the remelt of early formed crystals at lower levels of the magmatic reservoir. The possibility of assimilation of siliceous sediments was also suggested, but apparently not adopted. This last suggestion is criticised by BOWEN, who definitely explains the passage from the plateau magma-type to the nonporphyritic central magma-type as being due to the separation of crystals of olivine and basic plagioclase (85, p. 78). The absence of transitional types among the productus of eruptions is left without explanation by this hypothesis. Another suggestion was made by KENNEDY, who postulated the nonporphyritic magma-type to be the parent of the plateau magma-type (88). In his next paper, however, KENNEDY assumed both of these magma-types to be primary magmas and wrote that « there is no evidence that either of these ' primary ' magmas is a derivative of the other nor can we point to any common parent from which they could have been derived » (89, p. 256). This finally led him to postulate distinct crustal layers from which these magma-types were derived through a remelt (95).

Which of these hypotheses - differentiation, assimilation, or the remelt hypothesis is the correct one, is difficult to say at the present time. Perhaps all the three processes had their share in the diversification of the rocks in question.

2. — The mode of eruption of the lavas

The plateau lavas of Antrim, although covering an area of approximately 1500 square miles, are merely a fragment of a far more extensive lava field of the North

Atlantic or Thulean igneous province. The remains of plants in the interbasaltic beds prove that lavas were erupted under terrestrial conditions. The scarcity of volcanic ash suggests that the lavas were erupted without a great deal of violent volcanic explosions. These facts, together with the observations of the plateau lavas of the Western States of America by F. von RICHTHOFEN, led Sir Archibald GEIKIE to postulate the theory of fissure-eruptions. On the other hand J. W. JUDD was more in favour of the theory that the lavas were erupted from volcanoes of a central type. The fact that no dyke-feeders have ever been found in the British Tertiary igneous province, and the fact that all known suites of dykes cut the lavas, supports the recent conclusion of the Geological Survey, that the lavas were not necessarily erupted through dyke-fissures. Against this absence of dyke-feeders we have the numerous basaltic and doleritic plugs of Antrim - which may be considered to be the denuded remnants of volcanic vents infilled with the last portions of the magma that gave rise to the lavas. This suggests the conclusion that the lavas of Antrim belong to a multiple vent type of shield lava complex.

The lower lavas were poured out on a chalk peneplain covered with clay-with-flints. The eruptions followed one another and they were separated by long intervals during which the surface of the lava flows had time to weather out to laterite or red bole. The longest interbasaltic period happened at the end of the eruption of the lower lavas when the major interbasaltic zone was formed. The upper lavas were thus poured out on the surface of this interbasaltic lateritic zone. The presence here and there of lignite layers at the top of the lateritic zone suggests that the surface of the country towards the end, and probably during, the interbasaltic interval was covered with forest. No doubt streams and rivers were also active during this period and valleys were carved out in the soft lateritic zone and the underlying basalts. Thus, when the eruption of the upper lavas took place these valleys were infilled with the lava which also spread all over the surface. A surviving remnant of such lava-infilled valley is the Giant's Causeway.

A natural feature as phenomenal as the Causeway was bound to cause speculation almost as soon as it attracted attention. Already in 1771 Desmarest (14) suggested that it was a lava flow erupted from a volcano situated immediately to its south but, as has already been pointed out, this suggestion was based on an misinterpretation of Mrs. Drury's painting. A more important contribution was by Richardson, who, in 1803, discovered the correct stratigraphical position of the Giant's Causeway among the surrounding lavas. This is how Richardson described the cliff-face adjoining the Causeway : — « This whole face is composed of three strata, two of them formed of superb basalt pillars forty-five and fifty-five feet long, with an intermediate stratum, nearly sixty feet of another variety of basalt [e. g. entablature] ; the lowermost of these strata, when produced westward, dips, and at its intersection with the sea forms the Giant's Causeway. » (30, pp. 29-30). According to Richardson the Causeway is formed by the colonnade of the first (lowermost) flow. This interpretation was confirmed by Conybear and Buckland (39) and also by Du Noyer, who produced a diagrammatic section of the coast at the Causeway (47, fig. 8, p. 11). But Du Noyer made difficulties for himself by trying to correlate the ‘ amorphous basalt ’ beds, some of which are the lower lavas, while others are the entablatures of the upper lavas. One important observation made by Du Noyer was that « the columns on the east side of the Causeway, which is about one hundred and sixty feet across, incline to the east, while on the west side they slope to the west, thus showing in their vertical arrangement a radiation from a series of centres, all following a given line, which would have very nearly a meridional direction, or in other words that of the longest axis of a lava-flow » (47, p. 9). The Geological Survey Memoir, published in 1888 (65), did not add anything new to our previous knowledge of the stratigraphical position of the Causeway. The recent attempts by Rohleder to interpret the Causeway (81,86) suffer from several mistakes. He apparently has ignored the interbasaltic bed and made the two lowermost lava flows of the upper set of lavas into one flow (81, fig. 2, p. 248, fig. 4, p. 257; 86, fig. V, p. 12 and p. 14). To explain the position of the Causeway he postulated two faults running in NNW-SSE direction and forming a small graben (86, Map, Table XLIX), but strange to say in his N-S section of the Causeway (86, fig. 5 p. 259) these two faults seems to run across the southern end of the Causeway. None of these faults, however, are possible. Such faults would certainly be visible in the neighbouring cliff faces where the lavas are well exposed, and in point of fact there is no trace of faulting to be seen there. On the other hand Rohleder quite correctly inferred from the divergent inclination of the Causeway that here we have a lava-infilled valley (86, p. 259). This conclusion makes the introduction of faults quite unnecessary.

Although some kind of lava-infilled hollow is certainly suggested by the divergent arrangement of the columns of the Causeway, further and more definite evidence was discovered by the present writer. The basalt of the Causeway is resting not on the laterite of the major interbasaltic zone, but directly on the fresh olivine-basalt belonging to the lower set of lavas. The actual junction can be seen at a very low tide on the eastern side of the Causeway opposite « The Loom ». The exposure is not good, as it is covered by sea weeds, but samples collected show quite definitely that the columns of the Causeway rest on olivine-basalt lava.

In this connection is interesting to look at the old engraving of this locality. The engraving of 1776 (Pl. II, fig. 2) shows on the foreshore (right foreground to the right of the young lady selling flowers to two gentlemen) an outcrop of a rock which looks like the lower lava (compare Pl. II fig. 1). Above it is the columnar basalt of the Causeway. In the engraving of 1812 (Pl. III fig. 2) this outcrop appears to be denuded away, but the columnar basalt is resting on some dark rock, which also may represent the lower lava. At the present time the columnar basalt alone is visible at this spot and its base can only be seen at very low water.

This seems to indicate that at least 20-30 feet of the major interbasaltic zone as well as some of the lower lavas are absent from under the Causeway.

The cliffs immediately adjoining the Causeway are covered by screes, but the major interbasaltic zone is seen at the height of about 70 feet above the sea level at a distance of ¼ mile on each side of the Causeway. Assuming that the dip of the lavas would lower this zone in the direction of the Causeway, it is still impossible to place it less than 50 feet above sea level. This suggests that the valley excavated in the lower lavas and in the lateritic zone can not be less than 70 feet deep.

The inclination of the columns of the Causeway becomes even more pronounced in the southern direction. In the cliffs immediately south of the Causeway the columns dip at an angle of 30° (this is clearly seen in WELCH's photo, Pl. I, fig. 2). At the same time the colonnade as a whole is ascending the cliff. It is clear therefore that we must also assume a slope in the southern direction. The only explanation that suggests itself for this peculiar structural feature is that the Causeway represents a lava-infilled meander of a river, as illustrated in Fig. 2 giving a plan and two sections of Causeway.

Lava-infilled valleys are of common occurrence in volcanic regions. A classical example of such an occurrence is the Sgùrr of Eigg. Another example is that of Doon Point and Little Causeway on the eastern shore of Rathlin Island, Co. Antrim. Doon Point was figured by HAMILTON (21) and briefly described by HAUGHTON (43), and it is a very fine exposure of a lava with divergent curving columns. This lava, which belongs to the upper set, is here resting on a lava of the lower set. The major interbasaltic zone, which is visible only a few hundred yards away, is com-

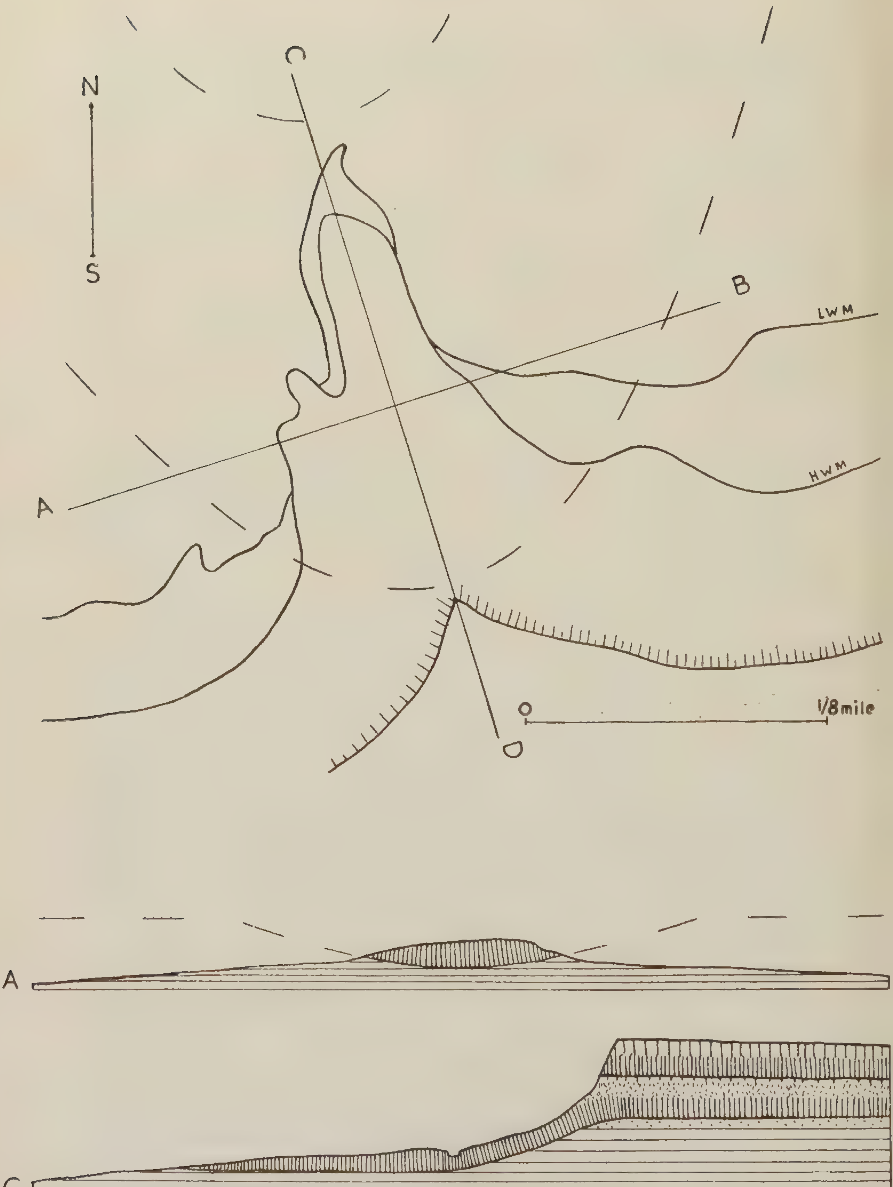

Fig. 2. — Plan and two sections of the Giant's Causeway. The two curves shown in interrupted lines on the plan indicate the hypothetical river valley meander excavated in the lower lavas and subsequently infilled by the lowermost flow of the upper lavas. LWM - low water mark ; HWM - high water mark.

pletely absent at this point. This, in my opinion, is a case analogous to that of the Giant's Causeway. Another probable lava-infilled valley occurs SW of Port Phadruig on the western shore of the Isle of Kerrera, near Oban, where two flows of mugearitic basalt of the Old Red Sandstone age are exposed in the cliffs. The Geological Survey Memoir (78) notes that the base of the lower flow is 60 feet deeper at the sea shore than in the adjacent cliffs and suggests that we have here a lava-infilled hollow formed in the underlying sediments. The lower lava at this locality, as in Giant's Causeway, shows radially divergent columns.

3. — The mechanism of formation of joints and of joint-systems

It is important to distinguish between the joints as such and the joint-systems. For example two kinds of joints form the joint-system of the colonnade : the vertical prismatic (hexagonal) joints and the transverse ball-and-socket joints. On the other hand the curvi-columnar zone of the entablature has a quite different joint-system, determined by curvilinear and branching joints.

At the outset one may assume that the joints in lavas are formed through the contraction of the material on cooling. A cooling homogeneous mass will tend to contract uniformly, in other words it will contract towards equally spaced centres of attraction and thus will give rise to a hexagonal network of joints. An approach to such a network is seen in the joint pattern of the colonnade. The joint pattern of the pseudo-columnar zone of the entablature is somewhat different, being formed mainly by vertical major joint-planes, thus giving rise to a pseudo-columnar structure.

The fissuring of a cooling material will take place only after the material has acquired a certain degree of rigidity, but the formation of fractures depends not only on the relative rigidity but also on the velocity of cooling, or rather on the velocity of the increment of the tensile stress.

Unlike the case of external loading, the stress developed through thermal contraction has no definite limiting value (tensile strength). Under certain conditions of cooling the material will fissure under the influence of small stress, while under other conditions the material may accumulate a very large tensile stress without fissuring (Prince Rupert's drops, armourplate safety glass, safety lenses). In all cases, however, fissuring will take place only after a certain amount of stress has been accumulated.

On fracturing, the potential energy of the accumulated stress is transformed into the surface energy of the fracture surface and the energy of heat and sound. It is probably safe to say that the major portion of the potential energy of tension is transformed into the surface tension energy. This means that the accumulated stress per unit volume is proportional to the area of the fracture surface per unit volume (specific surface). It follows, that in the case of a lava flow as described above, the smallest amount of accumulated stress was present in the pseudocolumnar zone of the entablature, where the joint-planes are wide apart (and the specific surface is therefore small). On the other hand the largest accumulated stress was probably present in the curvi-columnar zone of the entablature.

This is the first step towards the solution of the problem of the mechanism of formation of joint-systems. The second step must consist in the elucidation of the conditions of stress accumulation.

In a cooling material tensile stress can accumulate only when the material is incapable of yielding to shear or, in other words, when the viscosity of the material in question reaches a certain limiting value. There is no such thing, however, as a fixed fracture point, for the question of fracture or flow (brittleness or fluidity) is dependent on the time during which the effective force is acting. One can only define fracture point (vitrification point in the case of glass) in terms of a certain value of viscosity above which fracture becomes possible. In pitch, for example, fracturing may occur at viscosities greater than 10^5 poises, whereas in jellies the limiting value of viscosity must be very small indeed. In lavas the value of limiting viscosity has never been measured, but in technical glasses it is in the neighbourhood of 10^{10} poises. From the data on the viscosity of rock melts provided by KANI and VOLAROVICH one can infer that in a melt of basalt of the type of that of the Giant's Causeway this viscosity will be reached at about 900° C. The actual lava still retaining water and other volatiles would certainly be more fluid than the melt and this means that the temperature of its fracture point will be lower, if we consider the formation of glass alone. The presence of a crystalline phase would, on the other hand, increase the viscosity. In this connection it is important to know at what period in the cooling history of the lava crystallization does take place.

The work of TAMMANN (69, 79) has shown that in the majority of cases the number of crystallization centres formed per unit time reaches its maximum value at approximately 100° C. of undercooling, while the maximum value of the rate of crystallization is at 20° C. of undercooling. These are, of course, average figures which may not apply to a given mineral. This process is regulated by viscosity, and if viscosity is very high and the cooling rapid the melt solidifies as glass. The formation of glass does not, however, inhibit the formation and growth of crystals, although in that case the process may be very slow. In such a case there is a possibility that fracturing will occur before the end of crystallization or even before its beginning. The regular joints, the glossy surface of the joint-planes, the fine-grained texture, and the presence of patchy glassy mesostasis in the Giant's Causeway basalt-all this suggests that the fissuring took place while the rock was still in a semiglassy or even glassy state. On the other hand the olivine basalt lavas with their coarse structure, showing no glassy mesostasis and with a granular surface of the joint-planes, were probably crystallized completely before the fissuring took place. The same applies to the more fluid upper part of the tholeiitic lavas that show a pseudo-columnar structure.

The freshly opened joints of the lava is, in my opinion, an important criterion. Without exception the freshly opened joints in tholeiitic lavas show a glossy surface marked by parabolic, radiating, or feathery markings and in this respect resemble fracture surfaces in glass or analogous material. Microsections across these joints show a single or a multiple layer of fibrous palagonite, suggesting the former presence of glass. The amount of glassy and palagonitic mesostasis is also higher in the portions of basalt adjoining the joints, although the granularity is the same as in other parts.

The idea that solidification may take place at an early stage of, or even prior to, crystallization is by no means an unwarranted assumption. In all the experiments on the crystallization of molten basalt by WATT (32), HALL (34), FOUQUE and MICHEL LEVY (61), and HERMAN and RODWELL (64), the crystalline material was not obtained by the actual slow cooling of a basalt melt, but by the annealing below its softening point of the glass obtained from it.

Dr. J. A. SMYTHE kindly undertook on my behalf a series of experiments on the Giant's Causeway basalt. At 1400° C the melt of this basalt was quite fluid. Even slow cooling for 12 hours failed to produce crystals — the melt solidified as a perfectly isotropic glass (refr. index 1.573). The annealing of this glass was done at 900°-1000° C, a temperature which was probably too low for the crystallization of augite and feldspar. Three hours of annealing resulted only in the formation of few minute spherulites of a brownish mineral resembling wollastonite. It took an annealing of 36 hours to produce a spherulitic porcellanite-looking material composed mainly of wollastonite (?) and iron-ore in the form of minute granules and dust. The changes of the specific gravity of the material undergoing devitrification were as follows:

Basalt	2.838
Glass, cooled for 12 hours	2.756
» annealed for 3 hours	2.788
» » » 20 »	2.853
» » » 36 »	2.905

It is certainly impossible to draw any important conclusions from these experiments, first because of the anhydrous nature of the melt, secondly because the time of cooling was short, and thirdly because the temperature of annealing was considerably lower than the softening point of glass. A recent work of Tzvetkov (94), however, shows that by a process of annealing at suitable temperatures it is possible to produce a crystalline material resembling the original rock. It is not improbable, therefore, that under certain conditions of cooling, solidification may be in advance of crystallization. At the present time it is tacitly assumed that all igneous rocks have crystallized directly from liquid magmatic melts, but some forty years ago the leading British petrologists, such as Bonney, Judd, and Rutley, believed that the majority of acid and even some basic volcanic rocks acquired their crystalline structure through devitrification. It is well to remember in this connection that the crystallization of a given mineral out of magma is determined not only by ist solubility, but also by the viscosity resistence of the melt at the crystallization temperature and on the velocity of cooling. A slowing down of the rate of cooling in the labile region would favour devitrification, even if the viscosity is high. Harker wrote, that « devitrification is merely a long-deferred crystallization of the magma » and that « it is possible that crystallization hampered by the extreme viscosity, may take place at various stages during the original cooling of the rock » (71, p. 226).

The difference of the surface of the vertical joints of the colonnade and of the pseudo-columnar zone should, therefore, be attributed to the relative position of the fracture point in the crystallization range.

A higher amount of water in the upper part of the flow (Tables III and IV) would render this part more fluid than the lower part of the flow. This would mean that the fracture point in the upper part of the flow would be situated at a temperature lower than that of the lower part and that at the time of fracturing the greater part of the rock would be crystalline. But even in the upper part of the flow there is no trace of a fluidal arrangement of feldspar laths and this means that crystallization was complete only after the lava came to rest. On the other hand the fluidal bands of palagonite and chlorophaeite suggest that some sort of differentiation into a dry and a wet portion took place in the liquid magma prior to extrusion.

Another important feature of the joint surfaces deserves our attention. Almost invariably the freshly opened or even slightly weathered surfaces of the columnar joints exhibit horizontal bands 2-4 inches in width covered by faint parabolic lines or low ridges (Fig. 5). These peculiar bands on the surface of basalt columns were first noted by G. H. Cook in 1884 in the famous John O' Rourke' s quarry in New Jersey. In 1886 Iddings (63) compared these bands to layers of bricks or rude chiseling, but he gave no suggestion as to their probable origin. In 1920 James (75) described similar marks on the surface of lava columns in Australia. Apparently unaware of Iddings' work, he also compared them to chisel marks and suggested the term ' chisel structure '. He also, probably quite correctly, inferred that « the horizontal lines appear to represent successive stages in which the columns were formed, i. e. as cooling proceeded... » (75 p. 463). If we accept this interpretation, then the parabolic ribbings on the surface of the bands must be regarded as the tide-marks of the advancing fracture. Woodworth, in his detailed study of tension joints in rocks, has described a type of fracture under the name of ' feather fracture ' (66). It consists of finely outlined curving ribs or striations proceeding from a central midrib like the barbs of a feather. The ' feather fracture ' is, as a matter of fact, similar to the ' fast ' fracture in glass, as was demonstrated by PRESTON (80). On the other hand the 'chisel structure' in lava is similar to a 'slow' fracture in glass. PRESTON suggests that « these ribbings are clearly tide-marks or ripple-marks marking the intermittent advance of the fissure, and its hesitations while the stresses redistribute or accumulate » (80, p. 254).

This interpretation of the ribbings is of great value not only as an explanation of the structure of the joint-surfaces of the lava columns but also as a suggestion that the fracture does not start until a certain amount of stress has been accumulated and then proceeds with an explosive violence. This theory will be used in an attempt to interpret the joint-systems of the Giant's Causeway lava flows.

To understand more fully the implication of this theory one must consider the accumulation of stress in a cooling lava flow. Up to the fracture point any strain produced by cooling will be compensated by viscous flow, but beyond this point strain will give rise to a tensile stress that is bound to accumulate until either cooling ceases or fracture occurs. The tensile stress is, therefore, proportional to strain, which in its turn is proportional to the fall in temperature.

The temperature distribution in a cooling sheet of magma has been calculated by LANE (68, 82). His temperature-time curves can be easily transformed into curves showing the temperature distribution in the sheet at certain time intervals. This has been done in Fig. 3. Both the vertical and the horizontal scales are arbitrary in this diagram. The curves indicate the temperature reached by different points within the sheet at the ends of successive and equal time intervals. These curves, however, do not provide us with the necessary information as to the velocity of the movement of the isotherms. This velocity can be calculated by measuring the distance between two successive temperature-distance curves along the horizontal line corresponding to a given isotherm (Fig. 3). In this way the velocities of isotherms, 0.75, 0.50, and 0.25 of the initial temperature (T) have been calculated (Fig. 4). The curves of velocities thus obtained show, that proceeding from the margins to the centre, the velocity at first decreases and then approaching the centre increases. The curves thus show three maxima and two minima.

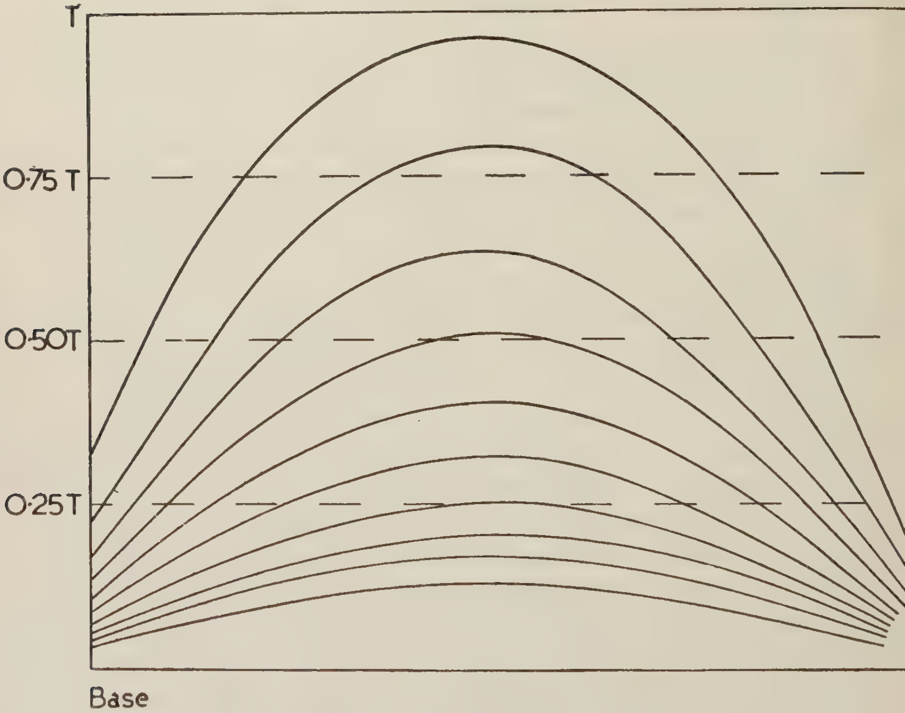

Fig. 3. — Temperature distribution in a cooling lava flow. T - initial temperature. The curves represent the temperatures attained in different levels of the flow at the end of successive and equal time intervals.

Another feature of these curves is that the minima of successive isotherms are displaced towards the margins of the sheet as we proceed from high temperatures to low temperatures. The two minima of these curves mark a change in the velocity increment of the isotherms, passing from deceleration to acceleration. The two marginal zones of the sheet are thus the regions of deceleration and the central zone that of acceleration. Now if we take a section of a tholeiitic basalt lava flow, we can see three zones each characterised by its own joint-system : the colonnade, the curvi-columnar zone, and the pseudo-columnar zone. There is nothing in the nature of the rock to suggest that the sharp lines of demarcation between these zones are due to the change in its mineral or chemical composition. One must therefore attribute them to the nature of cooling, and I would like to suggest that this change is related to the change of the velocity of the isotherms. As has already been mentioned, fissuring will become possible only after the advance of the isotherm corresponding to the fracture point - the fracture isotherm. The suggestion that I would like to make here is that the rate of advance of the fracture isotherm will determine the nature of jointing, while, the amount of the accumulated stress will determine its magnitude.

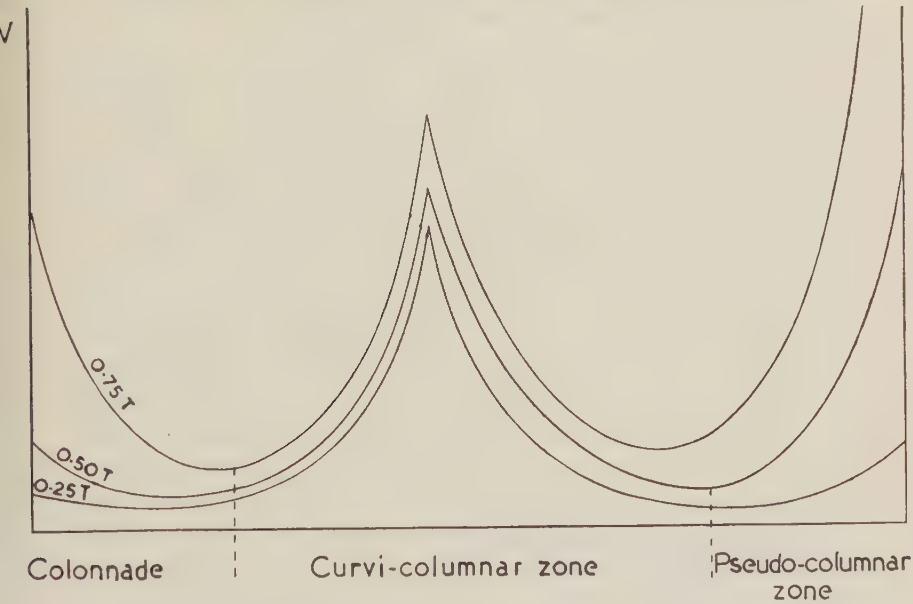

Fig. 4. — The velocity of the movement of the isotherms. The curves represent the velocity of the movement of isotherms 0.75 T, 0.50 T and 0.25 T in different levels of the flow.

In this connection it is important to realise that the breaking strength in material subjected to thermal tension may vary within wide limits and in certain circumstances may acquire a very high value, as for example in Prince Rupert's drops, ' armourplate' glass, and ' safety ' lenses.

On the basis of this theory one can outline the formation of joints in a lava flow in the following way. At the top of the flow the high initial velocity of the isotherms and the presence of a free surface will prevent the accumulation of stress. The specific joint-surface will therefore be small and the distance between joints wide. The fissuring will proceed downwards until the increment of stress will become so small that the fissuring process is temporary suspended. The fracture isotherm in the case of a more fluid upper zone was arbitrarily selected for the purpose of argument at 0.50 T. In this way the pseudo-columnar zone has been formed. A similar process will take place in the lower part of the flow, but the smaller initial velocity and the absence of a free surface will produce a greater accumulated stress and this will give rise to a more closely spaced set of joints. The jointing will also proceed ' *staccato-wise* ' - accumulation of stress - release - another accumulation - another release, etc. This will give rise to the banded ' chisel structure '. In the upper pseudo-columnar zone this ' chisel structure ' has not been observed as yet, but this may be due to the fact that only weathered joint-surfaces have been examined. The fracture isotherm for the lower zone has been arbitrarily selected at 0.75 T. In this way the colonnade will be formed. The minimum of the velocity curve will again correspond to a pause in the process of fracturing. Thus an unfractured central zone will for a time remain sandwiched between two fractured marginal zones. The advance of the fracture isotherms both from the top and from the base of the flow will nevertheless gradually increase the accumulated stress. Judging from the closely-set joints of this zone, one may infer that the accumulated stress at the moment of fracturing was large. What is the explanation of this delayed action ? The only suggestion that I can make in explanation of this phenomenon is to draw an analogy between the rate of increase of thermal stress and the rate of loading of glass rods as influencing their tensile strength. It was found by Apelt (90) and Smekal (93) that the increase in the velocity of loading of glass rods tends to increase the tensile strength of the glass. In the same way the curves in Fig. 4 show that the velocity of isotherms increases very rapidly in the central zone. If this analogy is admitted, then one can suppose that the fracture isotherms did actually penetrate very deeply into the central zone before fissuring took place. The overstrained central zone then fractured with an explosive violence which gave rise to a tangle of curviplanar joints.

According to this theory the relative thicknesses of the three principal zones are determined by the nature of the velocity curves. For example, a thin colonnade will be due to the shifting of the minimum velocity point towards the lower margin of the flow. This in itself may be due to a variety of causes - a relatively lower thermoconductivity of the underlying beds, the preheating of them by a previous passage of lava, etc.

It remains now to discuss the origin of the ball-and-socket joints. Since the 17th century, when these joints were compared to the articulation of crinoids or to bamboo-stems, their origin has tantalised speculative imagination, but the only reasoned attempts at explanation of this type of jointing were made by Thomson, Mallet, and Preston. Thomson (53) assumed that the ball-and-socket joints originated in a fissure which occured in the centre of the column and which advanced to the outside. This fissuring, according to him, was determined by the tension produced by the expansion of the outer part of the column under the influence of infiltration of water and the consequent formation of hydration products in the basalt. According to Mallet (55) the ball-and-socket joints were produced under the influence of a unilateral cooling of the columns. According to Preston (87) they originated in a fissure which started on the outside of the column and then rapidly spread around and inside the column. To explain the divergent orientation of the curvature of these joints PRESTON had to invoke an alternation of cooling-from below and from above. In my opinion each of these theories contains an element of truth. It is true that the fracture started inside the column (THOMSON), that it was determined by an unidirectional cooling (MALLET), and that the curviplanar surface was formed under the influence of a combined vertical tension and a horizontal shear (PRESTON). The study of basaltic columns in quarry exposures clearly shows that the curviplanar portion of the joint is an internal fracture and that the horizontal lip is a later fracture. Occasionally one may even find a portion of a column with an unopened lip-joint. Such cases are, however, very rare and none of the Causeway columns shows this feature. When such an unopened joint is opened by a hammer blow, the curviplanar portion of the joint shows a perfectly glossy surface with well marked radial ribbings, and the lip-joint shows a fresh granular surface. A great number of transverse joints, however, do not show a lip-joint at all or only small ledges at the corners of the polygon. Other joints show the curviplanar joint extending to one side of the column in the form of an escape plane, as it was admirably demonstrated by PRESTON. The appearance of the curviplanar joint surface is also of great interest (Fig. 5). Usually it is covered with radial ribbings emanating from a point situated somewhere in the central part of the column but not necessarily in its true centre. Occasionally at this point one can find a knob. THOMSON (53) thought that this knob was made of a different kind of rock - this assumption was probably due to the fact that this knob often shows a granular surface. It is also true that some columns of the Causeway have a small miarolitic cavity situated at the locus of the radiating ribbings, but this is quite another matter. The presence of such a cavity did obviously determine the position of the fracture, but fracture could also occur without the presence of such a cavity. The granular surface of certain knobs indicates that here we have an analogous case to the fracture of the lip-joint. The knob in that case was a connecting link between one joint-block and its neighbouring block.

Experimental reproduction of internal fractures in glass is not easy, because the shock of the initial fracture usually shatters the object of the experiment. The best approach to it was obtained by French (76), who quenched a pot of molten glass and in this was produced a system of radial croacks emanating from a central compact core six inches in diameter and stopping short of the surface.

As practically nothing is known about fractures produced by thermal stress, any theoretical explanation of the mode of formation of the ball-and-socket joints must be highly speculative. My own interpretation of the origin of these joints is built up on two maxims taken from Preston's theory of fracture. The first is that fracture starts in the region of maximum tension and the second that the head of an advancing fracture will try to maintain a direction which, whatever its variation, is always at right angles to the principal tension at that point. Starting from these assumptions, the ball-and-socket jointing of

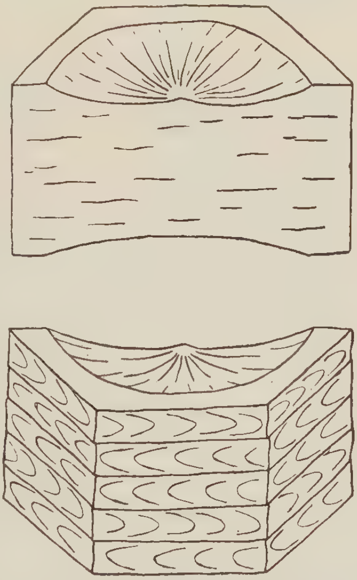

Fig. 5. — A diagramatic representation of a single block of columnar basalt bounded by ball - and - socket joints. The outside of the column shows horizontal bands with 'chisel structure'. The upper part of the column is a ball-socket joint with its lip, its central knob and radial stria. The vertical section shows horizontal streaks of chlorophaeite.

the Giant's Causeway basalt can be explained in the following manner. After the formation of columnar fissures which allowed a more rapid cooling of the sides of the columns, the distribution of temperature across a section of a column will be as represented in Fig. 6 (a). The outer part of the column on rapid contraction will be thrown into compression, while tension will gradually develope in the inner part of the column. The stress distribution during the cooling of the column is given in Fig. 6 (b), and after cooling - in Fig 6 (c). If the tension developed at a certain stage of cooling is sufficient to pro-

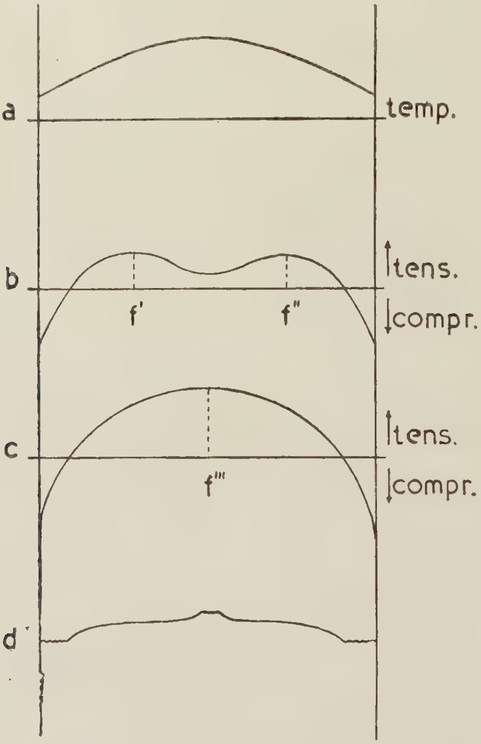

Fig. 6. — A diagramatic representation of the process of formation of ball-and-socket joints. (a) temperature distribution in a cooling column ; (b) stress distribution in a cooling column ; (c) stress distribution in a cooled column ; (d) section across the joint.

duce a rupture, then the fissure will start at the point of maximum tension - point f′ or f″ (Fig. 6 (b)), and once started it will rapidly spread round and then inwards and outwards. The fracture plane will be curved because the advancing head of the fracture will arrange itself perpendicular to the principal tension, which will be the resultant of the vertical tension, itself progressively decreasing with the growth of the fracture, and of the radial tension, decreasing in a lesser degree and only through the formation of the curviplanar joint. The curvature of the joint plane will, therefore, be determined by the delicate interplay of the principal stress components and it will require only a minute variation of one of them to direct it upwards or downwards. In the case if a fracture originating at point f′ or f″ there is a possibility that it will stop short of the centre and so determine the formation of a central knob, which during this stage will remain attached to the neighbouring joint-block. On the other hand if the fracture starts at point f‴ no such knob can be formed. The outward progress of the fracture will stop along the circular line corresponding to the region of zero-stress, but apparently quite frequently the fracture overshot its mark and gave rise either to a lateral escape plane or spread evenly to the margin of the column and so produced either a greatly reduced lip or none at all. The granular fracture of the central knob and of the lip is therefore of a later origin than the glossy fracture of the curviplanar joint.

This theory of the origin of the ball-and-socket joints suggests that like the vertical fissures they had their own rhythm, but that this rhythm acted as a kind of refrain to the vertical explosions which were always, in point of time, ahead of the transverse ones.

V. — Summary

The famous columnar basalt lava forming the Giant's Causeway, while it belongs to an upper series of olivine-free tholeiitic basalts, projects seawards at the base of high lava-cliffs at the level of and in contact with a lower series of olivine-dolerite lavas. Its anomalous position is explained if the lowest flow of the columnar upper series is regarded as having filled a river-valley excavated in a thick interbasaltic series of laterite and in the underlying lower basalt lavas.

The question of the origin of the lavas is discussed in this paper and two new chemical and a number of modal analyses are given, but attention is rather concentrated on the structural elements of the lavas.

A new terminology of the structural elements of certain types of lavas is proposed. The lower regular columnar zone is referred to as the ' colonnade ' and the upper part of the flow as the ' entablature '. In a fully developed flow the entablature in its turn is subdivided into a lower ' curvi-columnar ' zone and an upper ' pseudo-columnar ' zone.

The formation of these distinct zones — the columnar, curvi-columnar and pseudo-columnar — is dependent on the formation of their different joint-systems. These are here explained as part of the cooling history of the lava flow — as a result of the varying velocity of propagation of isotherms. The decreasing velocity at first gave rise to the columnar and pseudo-columnar zones. When the velocity reached its minimum, a pause in fissuring occured. This led to an accumulation of stress, and the hitherto unfractured middle zone fractured with explosive violence along curved planes, thus giving rise to the curvi-columnar zone.

The history of the cooling of the lava flow provides also an explanation of the transverse jointing — the famous ' ball-and-socket ' of the Causeway. Rapid cooling of the outsides of the columns would cause compression here and tension in the interior. The fissure would originate at the point of maximum tension somewhere inside the column and from that point would spread rapidly outwards, giving rise to a curviplanar joint. The horizontal lip-joint is suggested , on field evidence, to be of later formation.

It is presumed that fissuring took place while the lava was still in a vitreous or semi-vitreous condition and that the crystallization was more of the nature of devitrification.

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I. TOMKEIEFF. — *The basalt lavas of the Giant's Causeway district of Northern Ireland.*

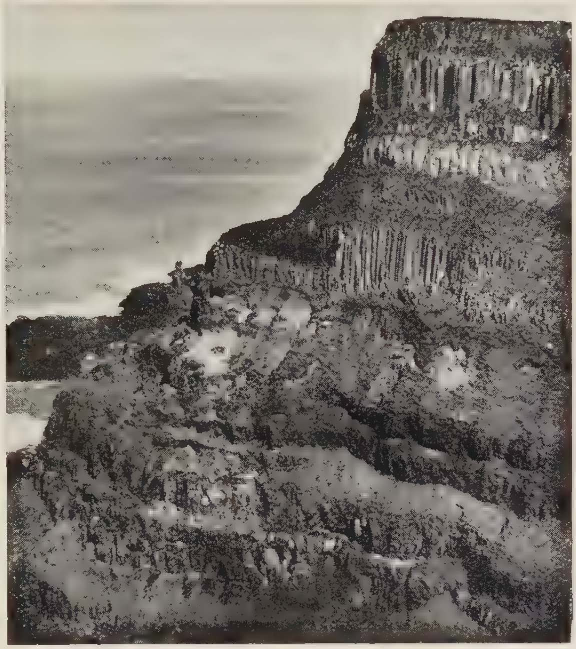

Fig. 1. — Pleaskin Head, shore east of Giant' s Causeway. Photo by R. WELCH. The lower part of the cliff is composed of lower lavas. The footpath is cut in the major interbasaltic zone. The upper part of the cliff is composed of two flows of the upper lavas.

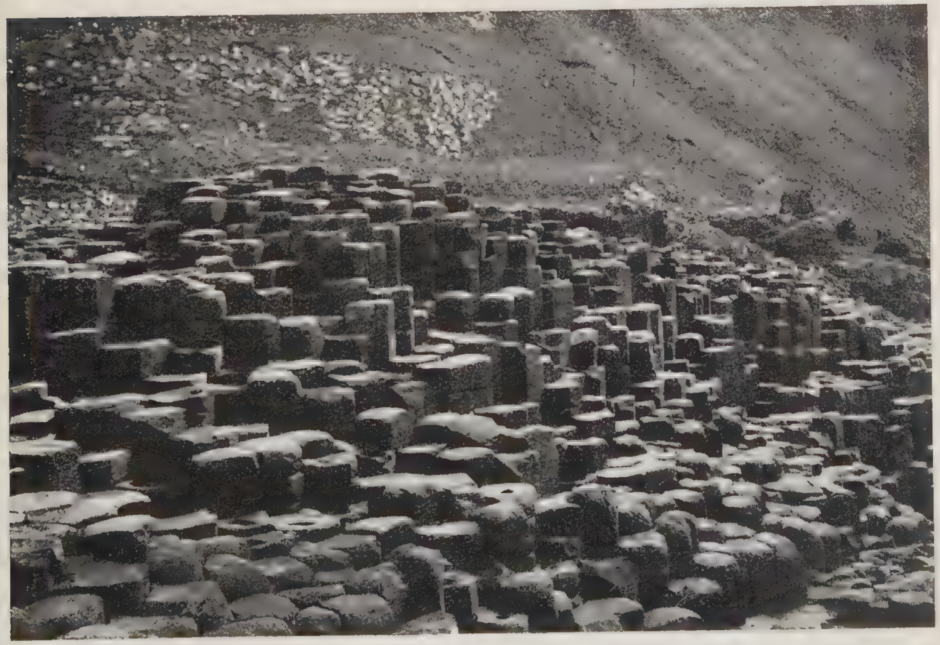

Fig. 2. — Giant' s Causeway. Photo by R. WELCH. The ball-and-socket jointing of the columns is clearly seen in the foreground. The tops of the inclined columns is seen in the cliff behind the Causeway. On the right, near the hut, large blocks composed of curvi-columnar basalt are resting on the foreshore. They are probably derived from the entablature above the inclined columns, a part of which is still visible in the upper part of the photo.

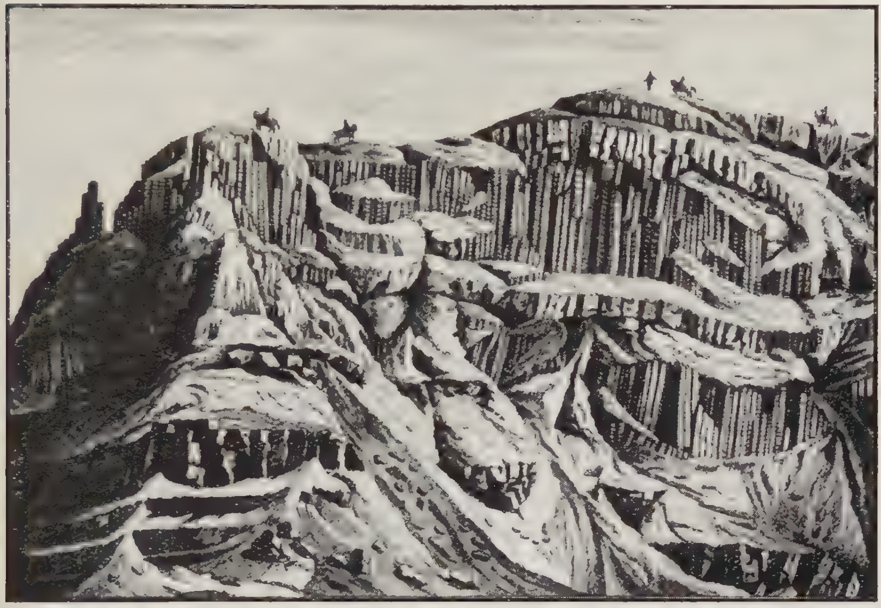

Fig. 1. — Cliffs adjoining Giant's Causeway. Drawn by Anton de BITTIO, Engraved by Jac. LEONARDIS, 1776 (41). Compare this engraving with photo Pl. 1, Fig. 1.

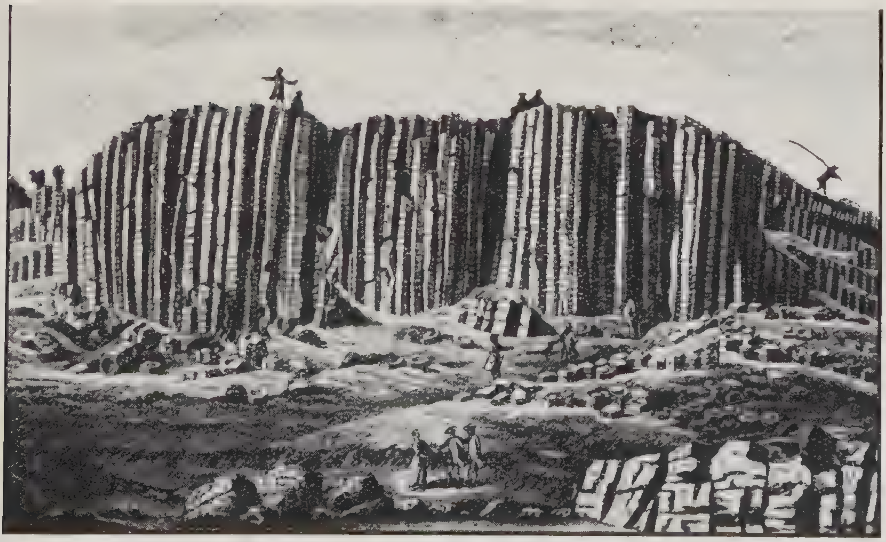

Fig. 2. — The Giant's Loom situated on the eastern side of Giant's Causeway. Reference-
me as for Fig. 1. The drawing of the rocks situated in the right foreground suggests that
ey are the lower lavas.

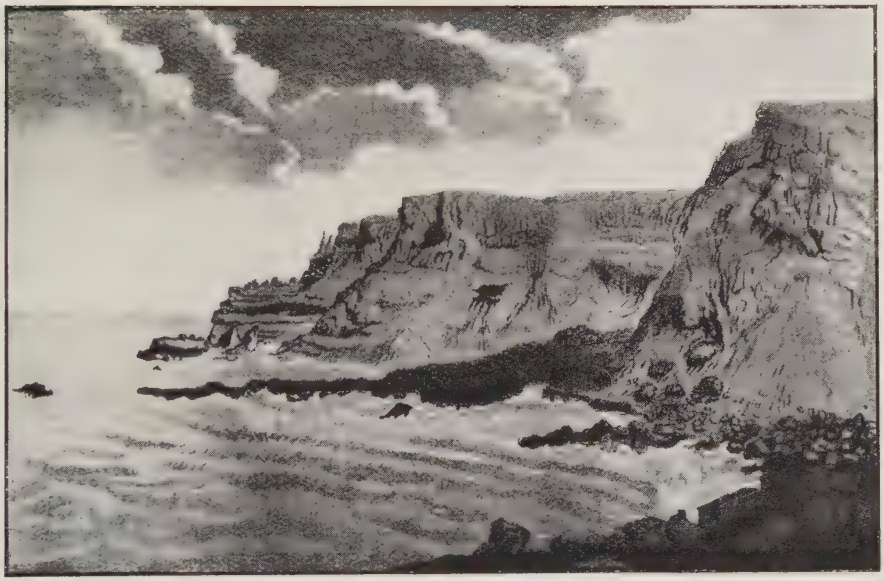

Fig. 1. — View of the Giant's Causeway from the west. Drawn by Halt Waring, engraved by J. Ford, 1810 (37).

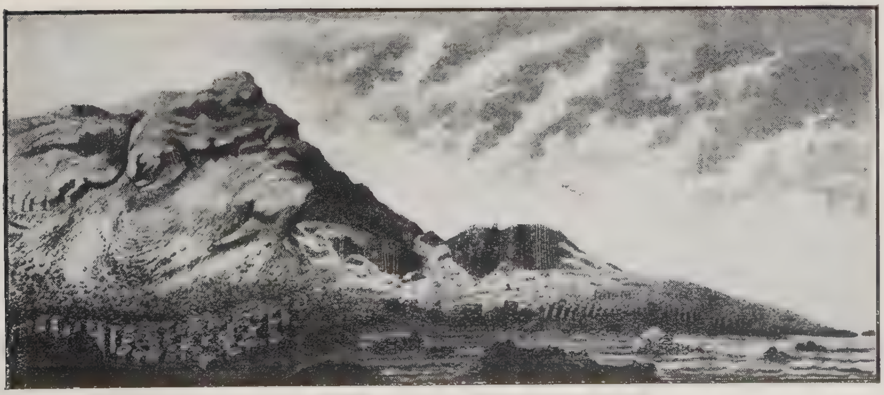

Fig. 2. — View of the Giant's Causeway from the east. Reference - same as for Fig. 1.
ompare 'The Giant's Loom' (below the birds) with Pl. 2, Fig. 2. Below the Loom the co-
umnar basalt rests on a dark rock which may be the lower lava.

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The nomenclature of pyroclastic deposits.

In approaching the question of pyroclastic nomenclature it is desired at the start to state that the author is indebted to a considerable extent to the writings of others, in particular to the classifications proposed by T. L. Bailey (1926) and by C. K. Wentworth & H. Williams (1932) [1]). In the latter publication the suggested usage of 36 terms is defined, and those definitions have been partly drawn on in the present paper. Wentworth & Williams also give a discussion of the work of earlier investigators, which is not repeated here. It is desired to place on record the author's indebtedness to Dr. J. E. Richey for sponsoring this paper, and to Dr. A. G. MacGregor and others who have given valuable discussion and criticism.

The present scheme is put forward with a view to discovering whether any general agreement is possible in respect of the limited terminology proposed. The scheme is not an elaborate one and no new terms have been introduced. It is hoped that it will provide a useful basis for discussion.

I. - Terms applied to loose pyroclastic materials.

Ejecta. — A general term for pyroclastic materials ejected from a volcanic vent (Holmes, 1928) [2]). 'Ejecta' is preferred to 'ejectamenta' if only because it is the shorter word. Ejecta may be classed as *cognate* 1), if they are directly derived from or related to the vent magma ; and as *accidental* 1) if they are of non-consanguineous origin (see definition below).

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[1]) A list of publications is given on p. 37. Authors referred to by Wentworth & Williams are there listed in chronological order.

[2]) Definitions adopted from various sources are indicated by the author's name or initials in brackets.

WENTWORTH & WILLIAMS (1932), following JOHNSTON-LAVIS (1886), recommend the use of the three adjectival terms *essential*, *accessory*, and *accidental*, which are defined as follows :

' essential ' refers to pyroclastic material " which is of immediate, juvenile, magmatic origin ".

' accessory ' denotes " pyroclastic materials derived from previously solidified volcanic rocks of consanguineous origin ".

' accidental ' indicates " pyroclastic materials derived from volcanic rocks, non-consanguineous with the magma involved during an eruption, or from other igneous, metamorphic or sedimentary rocks through which the vent was developed. These correspond to the *matériaux énallogènes* of LACROIX and the *allothigenous ejecta* of WOLFF ".

It will be seen that both *essential* and *accessory* are included in the term *cognate*, and while adopting the useful threefold division referred to above it is felt desirable also to retain ' cognate ' in the sense indicated. On this view therefore the grouping would be :

EJECTA

cognate } essential
cognate } accessory
accidental.

The terms should be applied only to ejecta and should not be used to qualify names descriptive of deposits.

Bombs. — Masses of magmatic material plastic at the moment of ejection and having forms, surface markings

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1) These two terms are also used by TYRRELL, 1928 (Glasgow), p. 289.

or internal structures assumed in response to forces or physico-chemical conditions acting during flight through the air. This definition is a modification of that proposed by Wentworth & Williams (1932, p. 46); it would cover certain breadcrust bombs described by Lacroix (1904, p. 523) and by MacGregor (1938, p. 561), whose texture, rather than shape, has been modified during flight. Variations referred to under the phrase « physico-chemical conditions » would include changes in temperature and pressure affecting the physical condition of the magmatic constituents, particularly water, leading to vesiculation. With it may be compared the definition given by Reck (1914-15): « Volcanic bombs are more or less plastic parts of an exploding magma ejected from a volcanic vent, which have suffered a systematic modification of their original form and structure as a result of mechanical forces acting during flight through the air ».

In size, bombs are more than 32 mm. in diameter (cf. p. 32). Varieties are named adjectivally according to their shape or other characteristics, and include *breadcrust bombs*, and spheroidal, rotational, spindle-shaped, explosive, Péléean, and other kinds. Small masses of lava « which assumed their characteristic forms while plastic and chiefly as a consequence of forces acting at the time of detachment from the magma or at the time of landing after flight » have been described by the adjective *driblet* (W. & W., 1932, p. 46).

Blocks. — Fragments of cognate or accidental material, larger than lapilli and usually angular, which have been erupted in a solid or nearly solid state. The huge blocks which are characteristic of *nuée ardente* deposits are believed by MacGregor to be composed of cognate material which in some cases was not fully consolidated at the time of ejection (1938, p. 31-33).

Lapilli. — Cognate or accidental ejecta ranging mainly from 32 to 4 mm. in size. This definition represents an extended use of the term as compared, for example, with Holmes' definition (1928), which speaks of lapilli as « fragments of lava », i. e. essential fragments only. It is believed however, that the broader definition conforms to the usage of many geologists and is to be preferred.

Mercalli (1907) distinguishes *dense lapilli* (lapillo pesante), formed of compact lava ; scoriaceous or *porous lapilli* (lapillo scoriaceo) ; and *crystal lapilli* (lapillo cristallino), all of which would be classed as essential. Under this general head would also be included thread-like lapilli and lava drops (e. g. *Pélé's hair*, *Pélé's tears*).

Cinders, or scoriae, are essential lapilli of a glassy or vesicular nature, and would correspond partly to Mercalli's scoriaceous lapilli. *Accretionary lapilli* are « pellets, often exhibiting concentric structures, owing to the accretion of fine ash or dust around raindrops falling through an explosion cloud, or to similar accretion around a nucleus fragment which rolls along the ground. These are the *mud pellets* and *pisolites* of other writers » (W. & W., 1932, p. 45).

Ash, (volcanic ash). — Unconsolidated pyroclastic material consisting mainly of fragments less than 4 mm. in size. The term *ash* without a qualifying adjective should be used only for material of cognate origin. Where it is possible to distinguish the essential, accessory, or accidental nature of the material, this should be stated.

Very fine volcanic ash, composed of particles less than .05 mm. in size, may be distinguished as *volcanic dust*, and the term is used for that grade of material in the scheme of classification which follows, where the need for such a distinction is felt in the case of the very fine tuffs.

The use of the term « ash » to connote a consolidated pyroclastic deposit is not to be recommended, although it has been done in the past ; the word *tuff* should be used in such cases, except perhaps where it is desired to retain an old stratigraphical name and refer to a group of pyroclastic rocks as « the..... Ashes ».

Volcanic sand & gravel. — « Unconsolidated sediments containing an admixture of volcanic detritus. The usage of these terms to denote the grain-size of pyroclastic ejecta of non-sedimentary character is to be deprecated » (W. & W., 1932, p. 50 ; cf. MURRAY & RENARD, « Challenger » Report, 1891).

Volcanic detritus is a more general term and would refer to fine pyroclastic ejecta which have been subjected to water sorting, and/or detritus largely derived from lavas, ashes or tuffs by such agencies of denudation as wind and running water. The term would include deposits of ash fallen into lakes or shallow seas, and would allow for some admixture of sediment derived from any kind of country rock.

II. - **Proposed classification of pyroclastic deposits.**

« The fragmental volcanic rocks are in general the products of explosive action » (HARKER, 1895, p. 239). The scheme of classification set out below has been drawn up on the principle that the main subdivisions should be based on the size of the component fragments ¹). The size limits are in the main similar to those used by WENTWORTH & WILLIAMS (1932, p. 51-2), being adapted from the grades for clastic sediments proposed by UDDEN (1914) and WENTWORTH (1922), which are accepted by TWENHOFEL (1932). The lowest limit of size has, however, been changed from 1/16 mm. to .05 mm. ; this avoids the writing of a fraction ²) and utilises the same figure as that adopted by HATCH & WELLS (1936) for the grain size of igneous rocks. Further groupings according to the nature of the material

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¹) WENTWORTH & WILLIAMS state that the primary characteristics to be taken into account in a classification should be : (1) Size of fragments. (2) Mode of origin. (3) Composition and texture. (4) Mode of deposition.

²) If it is desired to have each limiting size the same multiple of the preceeding one, values of 50, 5, 0.5, and 0.05 mm. could well be used. LACROIX (1930, p. 435) proposed to make 50 and 5 mm. the limits between blocks and lapilli, and lapilli and smaller fragments respectively.

are indicated under the appropriate rock-names in section III. The proposed subdivisions and names are as follows :

Limiting size of constituents forming more than half the bulk of the deposit.	Loose (unconsolidated) Materials.		Compact (consolidated) Deposit.	
32 mm.	Loose agglomerate or Agglomerate-ash.		Agglomerate or Agglomerate-tuff.	
4 mm.	Lapilli-ash.		Lapilli-tuff.	
0.5 mm.	Ash	Coarse ash.	Tuff	Coarse tuff.
0.05 mm.		Fine ash.		Fine tuff.
	Volcanic dust or Dust-ash		Dust-tuff.	

The names in the third column would apply to rocks of which more than half the bulk is composed of fragments whose dimensions lie between the limits indicated.

The rough proportions of fragments of different grades in a deposit may be denoted approximately by the terms « few » and « many ». Thus, a deposit described as « ash with few bombs », or « tuff with many lapilli », would convey a distinct meaning. When the bulk of any kind of fragment exceeded 50 % of the whole, the deposit would take the corresponding name from the classification, e. g. ‘ lapilli-tuff ’ would connote a rock of which more than 50 % was composed of lapilli. In this way it is thought that the above grouping may be made sufficiently elastic to include a wide range of pyroclastic rocks, of which there is admittedly great variety. In the following section an alphabetical arrangement is adopted for convenience.

III. - Terms applied to consolidated pyroclastic deposits.

Agglomerate. — Pyroclastic rocks containing a predominance of rounded or sub-angular fragments greater than 32 mm. in diameter, lying in a tuff matrix, and localised within volcanic necks (*Vent Agglomerates*) or at a distance therefrom. « The form of the fragments is in no way determined by the action of running water, as in volcanic conglomerates, but is a primary feature determined during the actual eruption » (cf. W. & W., 1932, p. 45). The presence of some angular fragments is not excluded by this definition. The majority of the fragments will be of cognate origin, but accidental ejecta may be present.

Agglutinate. — Tyrrell (1931, p. 66) uses this term with the following definition : « When plastic scoriae and blocks are ejected from a volcano, an accumulation of blocks resembling agglomerate may be formed by the coherence of the fragments as they solidify. The cement is then the thin glassy skin of the blocks at their point of contact. Such rocks may be called *agglutinate*, and may be distinguished from agglomerate by the presence of a glassy cement, by the occurrence of fragments of spalled-off scoria in the interstices between the blocks, and by the general absence of an ash cement ». It would appear from this definition that agglutinate may be thought of as a distinct variety of agglomerate. The type of deposit to which the term was intended by Tyrrell 1) to apply, is described by Perret (1924, p. 128 and plate 23) in the case of an eruptive conelet, « growing .... by the superposition of ejected liquid drops ».

Breccia (volcanic). — Compact pyroclastic deposits consisting mainly of angular to sub-angular fragments of

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1) Personal communication to the Author. Other examples of agglutinate have been observed in Iceland and in the Lower Carboniferous lavas around Glasgow.

agglomerate grade and with a matrix of tuff. As thus defined, the term would be rather more limited in its scope than according to TYRRELL's definition (1928, Trans. Geol. Soc. Glasgow, p. 290) : « The term volcanic breccia will be applied to material (mostly angular) resulting from the general shattering of country rock by volcanic activity, to accumulations of talus on the flanks of volcanic cones, to the products of mud-flows, and to pyroclastic material re-distributed by erosive action not long subsequent to its formation ». The definition given by WENTWORTH & WILLIAMS (1932, p. 46) reads : « More or less indurated pyroclastic rocks consisting chiefly of angular ejecta 32 mm. or more in diameter » ; these authors (*loc. cit.* pp. 30-32) also discuss the various meanings which have been given to the term in the past, including LACROIX's *brèches de projection* and other types. *Explosion-breccia* is a term introduced by TYRRELL (1928, Arran Memoir, p. 168), and the following definition is here suggested with his approval [1]: An explosion-breccia is a compacted deposit consisting of angular to sub-angular fragments of agglomerate grade, but with little or no fine matrix, which has been formed more or less *in situ* by localised volcanic explosions involving the shattering of country rocks and/or the auto-brecciation of intrusive igneous rock genetically connected with the explosive activity. An explosion-breccia is thus a special kind of volcanic breccia, and the term includes breccias formed in cylindrical, linear, or irregular explosion-vents.

Dust-tuff. — Indurated rocks composed of extremely fine pyroclastic material, i. e. made of dust particles (less than .05 mm., as defined on p. 30). The term has been used by BAILEY (1926), who points out that dust-tuff among pyroclastic rocks would correspond to 'tuffaceous shale' in the epiclastic group. It is felt that a name of this kind is needed and makes for clarity of expression when describing the very fine tuffs. Some Palaeozoic types

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1) Personal communication.

in Britain which have formerly been described as « china-stone ash » would now be termed dust-tuffs (Blyth, 1938, p. 397).

Lapilli-tuff -- An indurated deposit essentially made up of lapilli in a fine tuff matrix (W. & W., 1932, p. 47). When the fine matrix is abundant, i. e. its amount exceeds that of the lapilli, the rock may be called a ' tuff with many lapilli ' (see p. 32).

Tuff. — The definition given by Holmes (1928) is as follows : « A rock formed of compacted pyroclastic fragments, some of which can generally be distinguished as such by the naked eye. If the larger fragments exceed the size of walnuts the rock becomes an agglomerate, or a volcanic breccia ». Wentworth & Williams' definition reads thus : « Indurated pyroclastic rocks of grain generally finer than 4 mm. ; i. e. the indurated equivalent of volcanic ash or dust ». This definition is adopted, but it is also recognised that some admixture of fragments of country rock (sedimentary or otherwise) may be present in a tuff.

In the classification given on p. 32 it is proposed to divide tuffs into coarse and fine varieties, according as the greater part of the component particles are above or below .5 mm. in size. The distinction between a fine and a coarse tuff on this basis is useful in field work. For tuffs which are composed of very fine dust (less than .05 mm.) there is the term dust-tuff (*q. v.*).

Apart from, or in addition to, the above subdvisions, tuffs are classed as *lithic*, *crystal*, or *vitric* following the well-known grouping of Pirsson (1915). ' Lithic ' is an adjective applied to a tuff in which the fragments are mainly composed of previously formed rocks. ' Crystal-tuff ' indicates a rock « dominantly composed of intratelluric crystals blown out during eruption » (W. & W., 1932, p. 46). In the writer' s opinion the name should be allowed for rocks containing more than 50 % (by volume) of measurable crystal fragments, and instances of this kind have been described (Blyth, 1938, p. 400). Where both crystal and lithic fragments are present in considerable amount, the rock would be named a crystal-lithic-tuff or lithic-crystal-tuff according to which sort of fragments preponderated. ‘ Vitric ’, as an adjective, connotes the glassy nature of ejecta, which are usually small in size (shards) and grade down to the finest dust. Similar remarks to those under ‘ crystal-tuff ’ (above) would apply here to crystal-vitric-tuffs and vitric-crystal-tuffs. An adjective such as ‘ rhyolitic ’ or ‘ andesitic ’, denoting the general nature of the tuff, may with advantage be prefixed to the name. *Palagonite-tuff* is an instance where a particular constituent is indicated in the name.

Tuffaceous sandstone & tuffaceous shale are terms included in BAILEY’s classification (1926) to denote « epiclastic volcanic rocks composed wholly or in part of volcanic fragmental material which has been transported and redeposited by water ». The grades present would lie between .5 and .05 mm. in the first case, and below .05 mm. in the second. The terms would appear to be useful for rocks containing mixed pyroclastic and sedimentary materials (cf. ‘ volcanic sand ’), and are perhaps preferable to the name ‘ sedimentary tuff ’ which appears in WENTWORTH & WILLIAMS ’ list. (See also *Volcanic Conglomerate*).

Tuff-Breccia. — As defined by NORTON (1917), this is a « volcanic sub-aerial breccia made up of the fragmental products of explosive eruptions where the matrix consists of the finer materials of the eruption and in some instances has been washed in by mud flows ». In the present scheme of classification this term is omitted on the ground that, to many geologists, the name suggests a brecciated tuff. It would therefore seem preferable to discard it altogether.

Volcanic conglomerate. — Indurated coarse deposits consisting largely of rounded, water-worn material which is mainly volcanic in origin (i. e. contributed from the erosion of older volcanic rocks), but possibly with some admixture of pebbles derived from sedimentary or other country rocks. They may also be formed by volcanic mud flows and by the action of running water on freshly fallen ejecta (cf. W. & W., 1932, p. 50).

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Association of explosive brecciation and plutonic intrusion in the British Tertiary igneous province

(With 5 figures and 3 plates)

It is unusual to find explosion vents in association with plutonic intrusions belonging to the same period of igneous activity. In explanation, it might be supposed that, in general, plutonic intrusions are more deeply situated than the lowest level at which explosions can occur. Depth control, however, must be only one of several factors involved. It is accepted by some volcanologists at least that explosive brecciation may easily take place at a depth of as much as 2.000 metres below modern volcanoes [1]. Where it can be shown that plutonic magma has penetrated, without causing brecciation, to within this distance from the surface, say, to the base of a pile of coeval lavas less than 6,000 feet in thickness, other reasons must be sought. The problem has been approached from a somewhat different standpoint recently by Kennedy and Anderson (18), and a distinction has been drawn between plutonic masses in two different environments, termed respectively the plutonic and the volcanic association.

The volcanic class is well represented in the British Tertiary province where it has long been recognised that large deeply-eroded vents filled with agglomerate and breccia occurred side by side with plutonic intrusions, both being later in date than a widely spread suite of basaltic lavas.

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[1] The writer is indebted to Professor Signore for kindly giving his opinion as to this depth, as stated, and for references to literature (e. g. 2, 3).

In recent years it has also become increasingly apparent that explosions alternated repeatedly with plutonic intrusion. Sometimes it has even been possible to demonstrate a close relationship in time between these two contrasted types of igneous activity.

The occurrences which are referred to and compared in the present paper have, for the most part, been already fully dealt with elsewhere. For this reason descriptions will be confined to features which it is desired especially to emphasize.

Sequence of plutonic intrusion and explosive brecciation

Many of the successive events in the history of the individual Tertiary plutonic districts are displayed over relatively extensive areas, and very often the exact positions in the local time-scale of associated explosion-vents can be definitely fixed. An accurately dated plutonic mass may be broken through by a vent and have supplied shattered material to the agglomerates. An ensuing phase, such as a suite of cone-sheets, may represent the next episode in the intrusive cycle and, in another neighbourhood, its members may have been brecciated by explosions which, thus, are demonstrably of later date than the first. For other illustrations of the kind of evidence concerning age relations which is encountered in the field, the reader may consult fig. 2 and Pls. I and II.

The detailed sequence of intrusion and explosive brecciation can be made out for each district on substantial evidence and, as just remarked, a repeated alternation of the two phases is often apparent. A summary is provided in the following table. In this the arrangement in columns is merely for ease of reference and is not intended to imply contemporaneity of the occurrences listed in each.

Succession of Periods marked by Explosion and Plutonic Intrusion of Post-Plateau Lava Age.

	Explosion 1	Intrusion i	Explosion 2	Intrusion ii	Explosion 3	Intrusion iii	Explosion 4
I. Island of Mull (5, pp. 202-3)		A	A	A, B	A	A, B, A, B, A	A
II. Ardnamurchan (9, pp. 119-133 & 267)	A, I, ? B	B	A, I	B	A	B, I	
III. Island of Skye (See 10, pp. 73, 77 & 12, pp. 49-50)	A, I	B	A	A	A	? B, A	
IV. Island of Arran (7, pp, 111-112)		A, B, A	A	A			
V. Slieve Gullion 1) (11)		B	A, ? B	A	A	A	
VI. Carlingford (10, fig. 16 & p. 104)		B	A	A, B			

B = Basic, I = Intermediate, A = Acid Magmas: in the case of intrusive phases, order of letters indicates age-sequence.

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1) This early basic intrusive phase has been recently shown to be of Tertiary age by Dr. Doris Reynolds, to whom the writer is indebted for permission to refer to her results in advance of her publication.

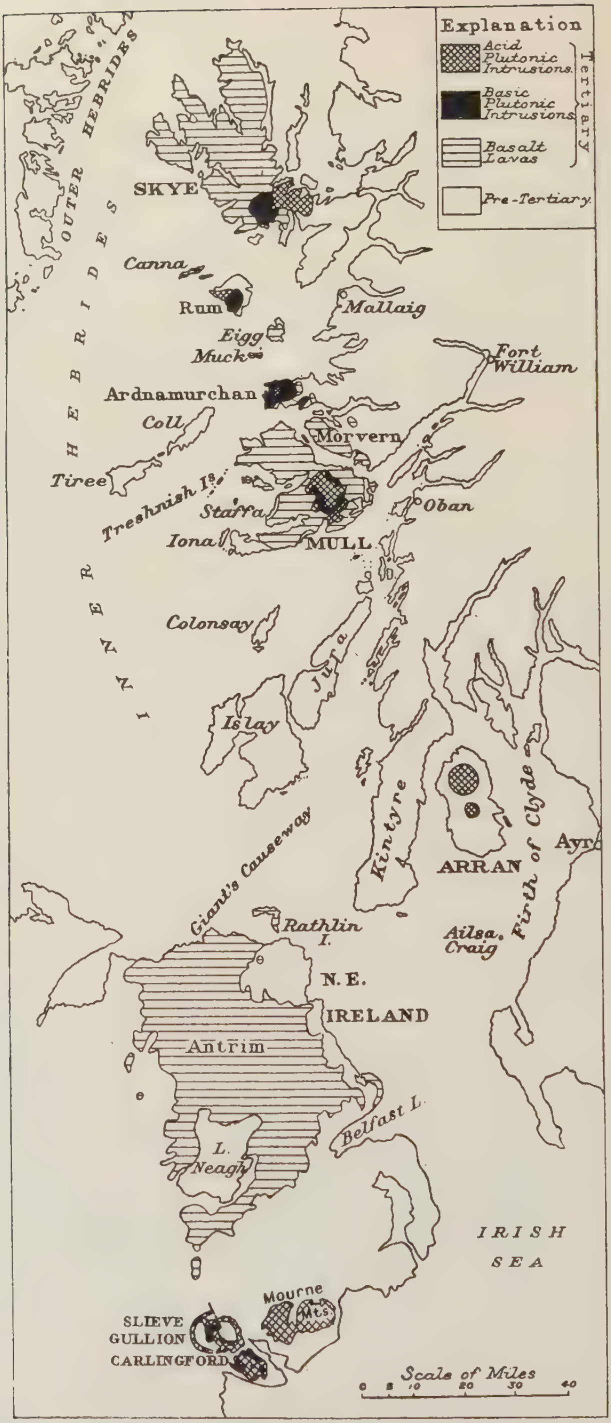

Fig. 1. — Map to show Tertiary plateau lavas and plutonic intrusions of Western Scotland and North-eastern Ireland.

Note: Agglomerates and breccias due to explosion occur within or near to the areas assigned to the plutonic intrusions in Shye, Ardnamurchan, Mull, Central Arran, Slieve Gullion and Carlingford.

A feature common to all the post-basaltic explosive eruptions is that each can be linked with the uprise of an acid or, in two or three cases, of an intermediate magma. Although, in two instances, more basic magma in addition appears to have been involved, the function of the more acid magmas as the main carriers of explosive gases is abundantly evident. In situations where explosion has not taken place, an excess of vapour, mainly water vapour, is indicated by the hydrolytic type of alteration which has affected the older rocks surrounding acid plutonic intrusions.

Occurrences of drusy cavities and of juvenile alteration products in the intrusive acid masses themselvesare further indications of the high water-content of acid magmas and, in some instances, of their association with substances such as fluorine (7, pp. 662 & 683).

On the other hand, except in special cases, no extensive explosive brecciation is known which can definitely be ascribed to the intervention of basic magmas, and the effects produced by basic plutonic masses upon their surroundings suggest the introduction of high temperatures unaccompanied by chemical changes markedly due to the action of vapours (e. g. Ben Buic gabbro, fig. 2). Occasionally an exception to this rule is supplied by quartz-gabbros but, in this connection, it is to acid veins extruded from their marginal portions that low temperature pneumatolytic alteration observed in adjacent earlier rocks is, in part at least, to be attributed. It is not ruled out that, within the plutonic districts, basic magmas at higher levels than the present surfaces of observation may have caused explosive brecciation. But known occurrences elsewhere accentuate rather than diminish the contrast. At the base of a series of basaltic lava-flows, such as the great Tertiary assemblage of the Inner Hebrides or the Lower Carboniferous Clyde Plateau Group of the West of Scotland, beds of basaltic tuff and agglomerate are well developed, but they do not recurr to a comparable extent at any later date. On the other hand, wherever more acid lavas are interbedded with the basalts, their common associates are beds of tuff composed of intermediate or acid materials. The richness of the basic magmas in potentially explosive gases at the inception of activity was, without doubt, due to a special set of conditions which permitted the upward migration of sparsely distributed volatiles and their concentration at the top of the magma column. The exception in this case helps to prove the rule.

While there is general uniformity in the kinds of magma responsible for the catastrophic eruptions, the effects vary considerably in different cases. As a rule the agglomerates are composed to a large degree of fragments derived from older rocks such as are found in the neighbourhood (Pl. III), and the quantity of acid or intermediate types representing the consolidated magmatic gas-carrier is usually subordinate. Notable exceptions are provided by the vents of Ben Hiant (II, 1 of Table) which were entirely cleared of country rocks before being filled in mainly with primary vent-products. In this case the vent walls are for the most part solid and unbroken (Pl. II, 2) but, elsewhere, brecciation of walls without apparent displacement of the shattered materials is more usual (e. g.

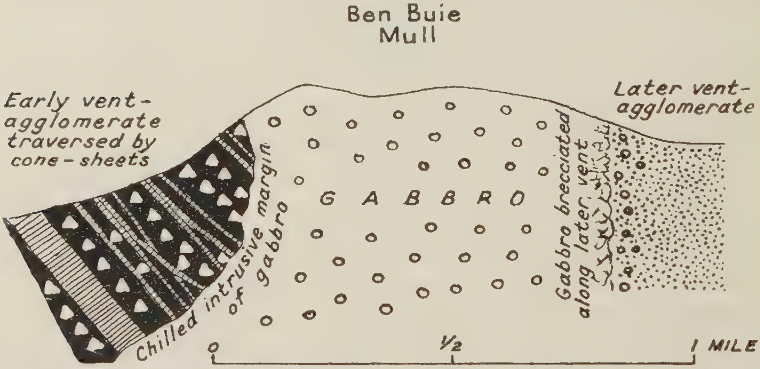
Ben Buie
Mull
Early vent-agglomerate traversed by cone-sheets
Later vent-agglomerate
Chilled intrusive margin of gabbro
GABBRO
Gabbro brecciated along later vent
0
1/2
1 MILE

Fig. 2. — Section across Ben Buie, Island of Mull, to show vents of first and second explosive periods, separated by intrusion of gabbro. [After G. V. Wilson, fig. 38,5].

II, 2) and, in some instances, is developed on an extensive scale (1, 2).

The intervals between the various periods of explosive activity would appear to have been of many unequal lengths, to judge by the relative complexities and extents of the intervening intrusive phases. Examples may be cited. In Mull, and also in Skye, wide spacing is evident. In both districts, a first and second series of vents are separated by the intrusion of a large mass of gabbro and of numbers of cone-sheets (Mull, fig. 2) while in Mull, between the second and third explosive phases, an even longer intrusive period intervened. This interval is marked by an alternation of plutonic (usually ring-dyke) and hypabyssal (conesheet) intrusion, many times repeated, and a shift of the focus or centre of magmatic activity on two occasions. In the case of Slieve Gullion (fig. 4), brief intervals seem clearly to be indicated by the fact that a single ring-dyke fracture served for the three intrusive and two explosive episodes listed in the Table. In Ardnamurchan, the interval between the first and second vent-periods was probably brief and, indeed, the two may have overlapped. But a long era of ring-dyke and cone-sheet intrusion, including a shift of centre, intervened before the third explosive episode, or episodes, occurred.

In the districts where more than one explosive period is known, the effects appear to suggest the occurrence of progressively more deep-seated conditions as time went on. In Mull, the two earlier episodes are marked by the formation of extensive craters choked with debris of country rocks, and the last merely by local brecciation of an acid ring-dyke. In Ardnamurchan (fig. 3) the evidence is still more suggestive. The first episode (Ben Hiant) is indicated by open craters, the second (Northern vents) by vents of the choked crater type associated with intrusions of plutonic dimensions, yet with hypabyssal crystallizations ; the third, in one case (Beinn nan Ord, see p. 168), by the comminution of a ring-dyke with relatively little displacement of materials followed by injection of acid magma on a mi-

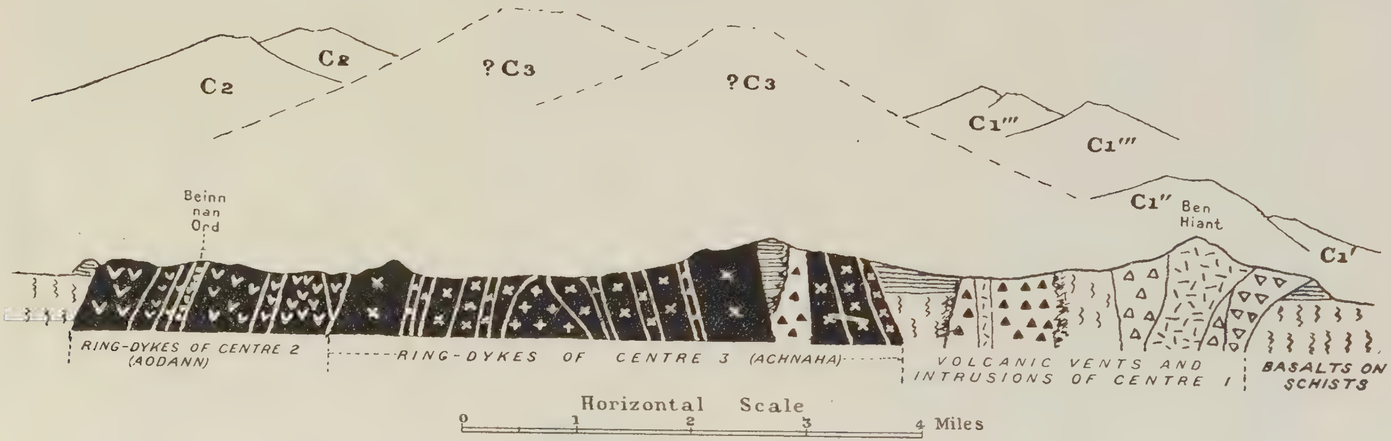
C2
C2
?C3
?C3
C1‴
C1‴
C1″
Ben Hiant
C1′
Beinn nan Ord
RING-DYKES OF CENTRE 2 (AODANN)
RING-DYKES OF CENTRE 3 (ACHNAHA)
VOLCANIC VENTS AND INTRUSIONS OF CENTRE 1
BASALTS ON SCHISTS
Horizontal Scale
0
1
2
3
4 Miles

Fig. 3. - Orizontal Section across the three successive Ring Complexes of Ardnamurchan, Scotland, with supposed overlying volcanic mountains of Tertiary times (related to centre 1: C1′, early vent of Ben Hiant; C1″, later vent of Ben Hiant; C1″, Northern Vents; related to centre 2: C2; hypothetically related to centre 3: ? C3).

[Section redrawn from fig. 20, Guide to the Geological Model of Ardnamurchan. Mem. Geol. Surv. Gt. Brit., 1934].

nute scale, in another, probably somewhat earlier (Glas Eilaan, p. 171), by brecciation of country rocks, also with little displacement, and with veining by acid tuff. In Skye, the first episode is associated with acid and intermediate lavas, the second with vent-infillings of brecciated older plutonic rocks, the third with intense brecciation and comminution of plutonic rocks probably not far displaced.

Perhaps the successive changes in character indicated by the sequences in Mull, Ardnamurchan and Skye are to be interpreted as the result of progressively more deep seated situations beneath a gradually accumulating superficial cover of lavas and ashes (see fig. 3). These districts would appear to provide unrivalled opportunities for examining explosion-vents at different crustal levels.

Types of explosive activity

It is suggested that the examples of more or less deeply seated explosive activity encountered in the various plutonic districts may be divided into three groups, according to whether the brecciation may be inferred to have preceded, accompanied, or followed the appearance of magma at the particular level concerned.

In the first case, gases given off from and preceding their magmatic carrier were presumably concerned. In the second, magma was present at or about the level at which explosions were occurring. In the third, consolidation of magma suitable as regards composition and situation may have led to the release of vapours to which the explosive action may be attributed. Examples of these three groups may be described in some detail and, at the same time, a distinction between the broken products may be drawn dependant upon whether they have or have not suffered considerable displacement. The examples selected are from places with which the writer is personally familiar, but many others might be quoted.

a) **Explosions preceding intrusion of magma.** — The earlier suite of agglomerate-filled vents of Slieve Gullion in North-east Ireland provides a good example of explosion, with displacement of materials, followed by intrusion of magma (11, pp. 805-817). The phenomena are restricted to the south-western quarter of a ring fracture which was completely marked out, at a later stage, by further brecciation and intrusion (fig. 4).

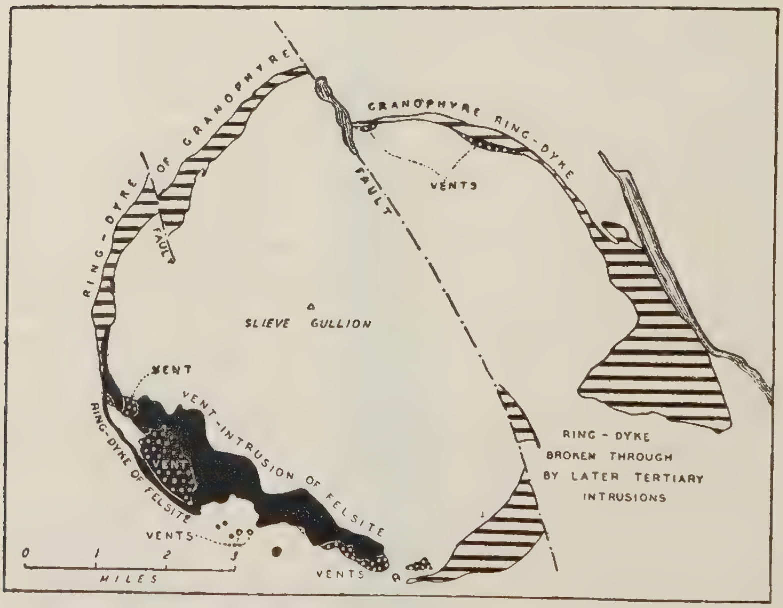

Fig. 4. — Sketch Map to show the volcanic-intrusive Ring around Slieve Gullion, North-east Ireland.
[Reproduced from Fig. 9, 15].

The agglomerates are practically entirely composed of fragments derived from older rock-masses in the neighbourhood and the intermingling of different varieties, as well as the normal agglomeratic structure, shows that the fragments were displaced by the explosions from their original surroundings. A rock which may belong to a vent-magma is a quickly cooled felspar-phyric andesite or basalt, in which the number and size of the phenocrysts varies greatly in different fragments (11, p. 802). This type is known elsewhere only from vents (16, p. 14) but has affinities with leidleite which occurs as sills in Mull (5, pp. 281-2). It is, however, to an acid magma, which is represented in a succeeding elongate mass of felsite intrusive through the vents, that the gases responsible for the explosions are most largely, if not entirely, to be ascribed.

It was noted by Nolan who, in the early ' seventies of last century, mapped the district for the Geological Survey that, in places, a felsite similar to this intrusion formed a matrix in which the agglomerate blocks and smaller fragments were embedded (1). The felsite was not acting in an ordinary intrusive manner, and it appeared to Nolan that the acid magma had followed closely upon the explosions, before any consolidation of the agglomerates had taken place, and so had inserted itself intimately between adjacent blocks and fragments. There seems every reason to accept his conclusions and to draw the further inference that the acid magma was the carrier for the gases which caused the brecciation (11, p. 810). The felsite intrusion is itself not known to be brecciated by explosion, except perhaps very locally, and its unusually fine texture for so broad a mass suggests not only rapid cooling but also a paucity of volatiles. Throughout its outcrop, even in chilled partly vitreous margins, phenocrysts of quartz and felspar are present, and these therefore had grown prior to the final emplacement. Comparison may be made with the porphyritic and very slightly miarolithic rocks composing the spine of Mt Pelé and the intrusion of the Soufrière Hills in Montserrat (19, pp. 65 and 72), making allowance for the slightly deeper level to be assigned to the Slieve Gullion intrusion.

It seems appropriate here to draw attention to another phenomenon which the hypothesis of the upward migration of volatiles in a magma column may serve partly to explain 1). In a complex of granite intrusions that are

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1) The writer would suggest that this hypothesis might now be accepted as a principle and that it would be most suitably coupled

practically identical in mineralogical composition, such as that of the Eastern Mourne Mountains (7, p. 659) or of Northern Arran (8, p. 149), the fine crystallizations assumed by an interior and later intrusion are a striking contrast to the coarse grain of an outer and older mass. If the magmas were, in fact, identical in their constitution, it is in the later mass, blanketed by the earlier from cold surroundings, that we might expect to find coarser textures. If, however, it is assumed that the volatiles streamed upwards towards the top of the magma-reservoir or intruding magmacolumn, the contrast in textures finds a logical explanation, although various other factors may be involved in each particular case.

As an example of brecciation due to advancing gases accompanied by little or no displacement of materials, the greatly shattered walls of many of the vents in Mull and Ardnamurchan may be mentioned. An explanation of such ‘ authigenic explosion-breccias ’ put forward by G. W. Rust (16) may be applicable in the present case, the mechanism consisting of the following stages : (1) Vapour tension in wall-rocks approximately equals that of the vent-magma ; (2) A major vent-explosion leads to relief of vapour tension in magma ; (3) This is followed by relief of vapour tension in wall-rocks and by their brecciation.

From presumably still deeper levels may be quoted the case of a brecciated eucrite ring-dyke belonging to centre 3, Ardnamurchan (see fig. 3 (Beinn nan Ord) and 15, fig. 7). This elongate intrusion of basic gabbro, about 150 yards in width, is absolutely comminuted along a length of nearly 2 miles. The finely divided breccias nowhere show that streaky appearance due to mylonitization which is characteristic of crushed rocks, of which good examples affecting an older intrusion occur in the same neighbourhood (9, pp. 265, 267, 270). They are, with little hesitation, attributed to deep-seated explosion. In

with the name of Professor Daly, in view of his convincing exposition of it (6, p. 78 etc.).

most places the comminution is so complete that single crystals of felspar have been broken into numbers of tiny pieces (fig. 5). Where, as often happens, the original boundaries of the crystals are retained, it is apparent that displacement has not occurred at all. In the same rock-slice or in adjoining exposures, however, intermingling may be apparent, the rock being constituted of a medley of broken grains mainly of felspar and augite. It seems clear, from the following observations, that the explosions did not lead to the projection of the broken material into the air :

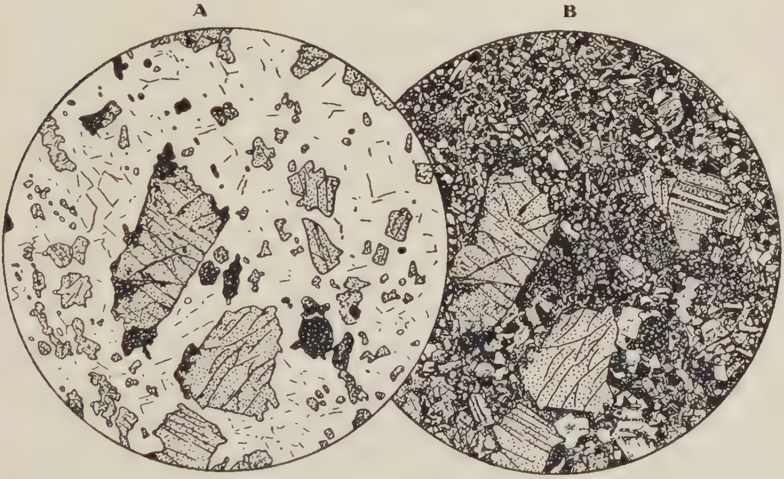

Fig. 5. — Shattered Eucrite of Beinn nan Ord.

A × 20. Irregularly bounded and broken crystals of olivine with some augite in a felspathic matrix. Ordinary light.

B × 20. The same field between crossed nicols, showing the shattered character of the matrix. Subsequent metamorphism attended by recrystallization has, to a certain extent, reduced the original intensity of the cataclastic structures.

[Rep. from H. H. Thomas, fig. 38,9].

1.º The brecciation extends to an adjacent and later ring-dyke of quartz-gabbro, and the original junction of the two intrusions can be satisfactorily mapped by an abrupt change in the lithology of the brecciated rocks. That this line does, indeed, mark the original contact follows from the fact that, when produced in either direction, beyond the area of brecciation, it joins on to unbroken contacts between the two intrusions.

2.º Within the outcrop of the eucrite, no broken materials other than those which could obviously have been derived from the eucrite are encountered.

Tenuous granophyre veins inserted between the brecciated materials suggest that the explosive gases were given off from an acid magma , and its representation in bulk at a deeper level seems indicated by the welding of broken crystals by recrystallization due to an accession of heat. The re-heating cannot be ascribed to any later intrusion in the vicinity, since the latest visible ring-dyke is here the adjacent quartz-gabbro the intrusion of which, as mentioned above, preceded the brecciation.

b) **Explosions accompanying intrusion of magma.** — In this subdivision are included the majority of the Tertiary vents and, although the actual presence of magma at the site of the explosions is not often directly demonstrable, this is a fair assumption since its consolidated products usually form a conspicuous proportion of the vent-infillings. Two varieties within the group appear to be represented at our present level of observation, one of these by a few vents which, at one time in their history, possessed open craters, the other by vents so choked by fragments of older rocks that it seems doubtful if they were ever completely cleared of these accumulations. It is possible that the second variety represents a cross-section at a lower level than the first. Extensive lateral brecciation of vent-walls, in their case, appears to provide one basis for the suggestion.

The vents of Ben Hiant, Ardnamurchan (fig. 3; Pl. II; and 15 fig. 7), furnish the type examples of the first variety (9, pp. 120-129, and 16). The occurrence of quickly chilled acid, intermediate and also basic particles among the ingredients of the pyroclastic infillings supplies a demonstration of the general conclusion that magma accompanied explosion, another indication of which is afforded by the interbedding of pitchstone lavas with the pyroclastic rocks.

The so-called Northern Vents of Ardnamurchan (15, fig. 7), which are probably slightly later than the Ben Hiant group (p. 163), belong to the second variety (9, pp. 129-131). In addition to prevalent fragments of earlier rocks, which are sometimes of great size, there are many of trachyte of various types and of rhyolite, all exactly comparable with those composing the Ben Hiant agglomerates, as well as of various intrusive Tertiary rocks not found on Ben Hiant. The mixing of this varied assortment of rock-fragments is usually thorough, so that great displacements of brecciated materials must have taken place. The mixing may be explained by supposing either that all the materials were actually projected into the air or that avalanching of vent-walls brecciated *in situ* by previous explosions was prevalent during outbursts in which magma and its consolidated products were involved.

An instance in which relatively little intermixture of broken materials appears to have resulted is supplied by the narrow, linear vent of Glas Eilean (15, fig. 7), which was probably active during the earlier part of the period related to centre 2, Ardnamurchan (9, pp. 131-133). The vent is represented by an elongate mass of breccias made up of broken-up Moine schists, Mesozoic sediments, Tertiary basalt lavas and accompanying cone-sheets. These materials are confined mainly to separate parts of the vent, where they would appear originally to have occurred. As a further indication of relatively slight displacement, in parts of the vent at any rate, may be cited the fact that highly brecciated narrow belts of quartz-dolerite, evidently representing cone-sheets, can be recognised among equally broken Mesozoic sediments. A pale acid tuff containing shards of glass, etc. has been injected as a matrix between the broken materials, and the explosions, therefore, were evidently accompanied by magma. A feeder for an eruption perhaps later than the tuff-injection may be recognised in an elongate dyke-like intrusion of fluxion rhyolite which traverses the vent materials parallel to the long axis of the vent.

c) **Explosions following the intrusion of magma and its consolidation.** — It is to America that we owe the development of the idea that gases freed from magma by the process of crystallisation may be the cause, in various cases, of explosive activity, and the principle is so well founded that qualification here is perhaps hardly necessary. It may be remarked, however, that the slight evidence from Scotland bearing upon the matter appears to suggest that an adequate supply of gases is obtained by the relatively rapid crystallization effected in small intrusions, and that, in the case of plutonic masses, the gases, though very large in total quantity, are released over a long period and so are rarely, if ever, sufficiently concentrated to be capable of brecciating their surroundings.

For example, local explosions are associated with a basalt sill connected with the Lower Carboniferous volcano of Arthur's Seat, Edinburgh (4, p. 228, and see 14). Not unlikely, too, some of the brecciation that affects certain basaltic plugs of the Scottish Lower Carboniferous lava-plateaus belongs to a period immediately following upon a rapid consolidation of the magma. In the Tertiary province it is less easy to discern possible occurrences, although in the environs of the plutonic complex of Central Mull some local explosions involving basic dykes may be cases in point (5, pp. 364-5 ; 13, pp. 78-9). Also, many examples referred to group (b) may partly belong here, for the following reason. Magma remaining in the throats of vents after an explosive eruption may be presumed to solidify from above downwards. The released volatiles from a solidifying melt may pass into the adjacent underlying magma. If so, a gradual increase would be produced in the vapour tension of the magma, culminating in a renewed outburst (11, p. 18; see also 20).

The general paucity of evidence from the Tertiary ring-dyke-vent complexes is all the more disappointing since these are in other respects among the most instructive examples of their kind. Both acid and basic masses are known which extend below a roof of older rocks and which have not been responsible for brecciation, although depth does not appear to be inhibitive since explosions approximately of the same age have affected other rocks in the neighbourhood. In illustration, such intrusions as the quartz-gabbro of Faskadale in Ardnamurchan (9, p. 185) and the granophyre of Beinn a' Ghràig in Mull (5, p. 342) may be cited.

The views expressed in this paper in regard to the explosive phenomena encountered in the British Tertiary province are put forward somewhat tentatively, and it is hoped that interpretations may be furthered by evidence from other denuded volcanoes. With the restricted vertical sections available in our Tertiary districts, probably few aspects of the problems involved, and these only dimly, can be discerned.

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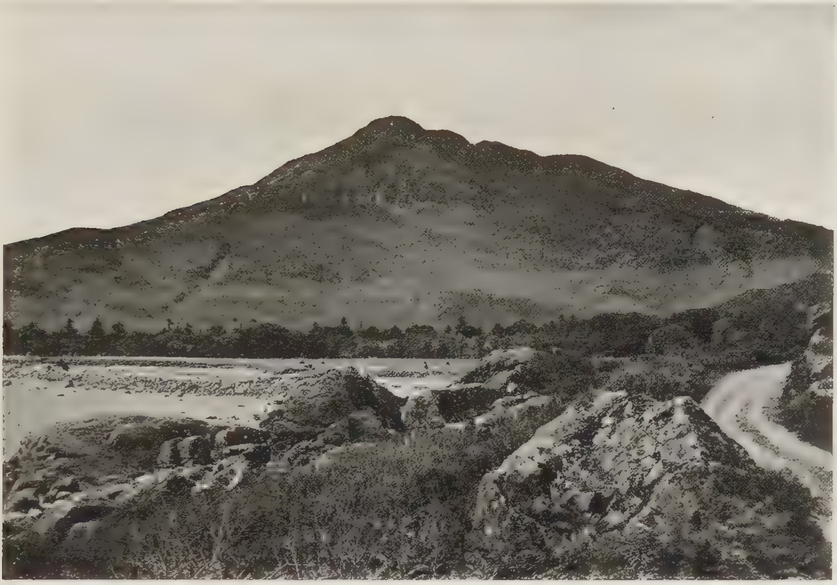

Fig. 1. — View of Ben Buie, Mull, a mountain composed of gabbro (along summit ridge) intrusive in agglomerates (forming lower slopes) belonging to the earlier vents and cut by pre-gabbro cone-sheets.

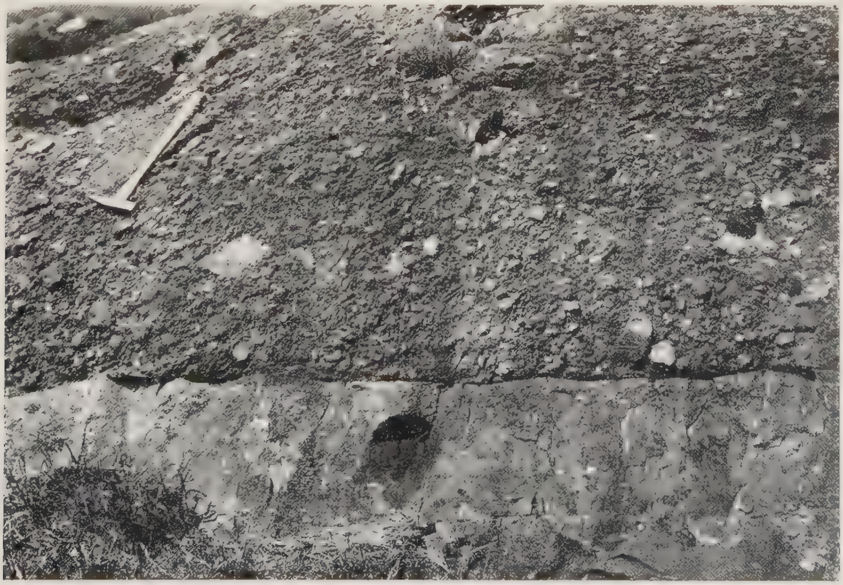

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Fig. 2. — Fine grained agglomerate belonging to the earlier vents and cut by a cone-sheet, which is inclined directly away from the camera, Beinn Bhearnach, Mull.

INTRUSIVE - EXPLOSIVE SEQUENCES FROM ISLAND OF MULL, SCOTLAND.

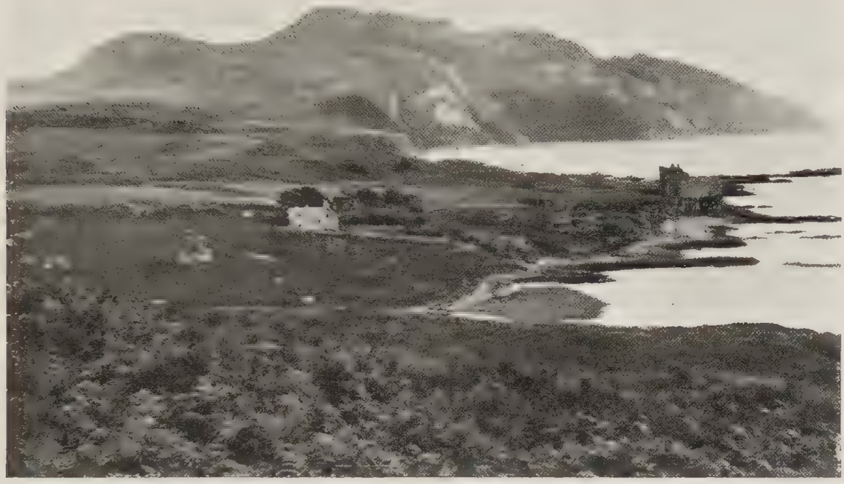

Fig. 1. — View of the west side of Ben Hiant, a mountain composed of a large intrusion dolerite in a group of explosion-vents. Promontory at extreme right of Ben Hiant is Maclean's ose, formed of interbedded agglomerate and tuff which fill the later vent.

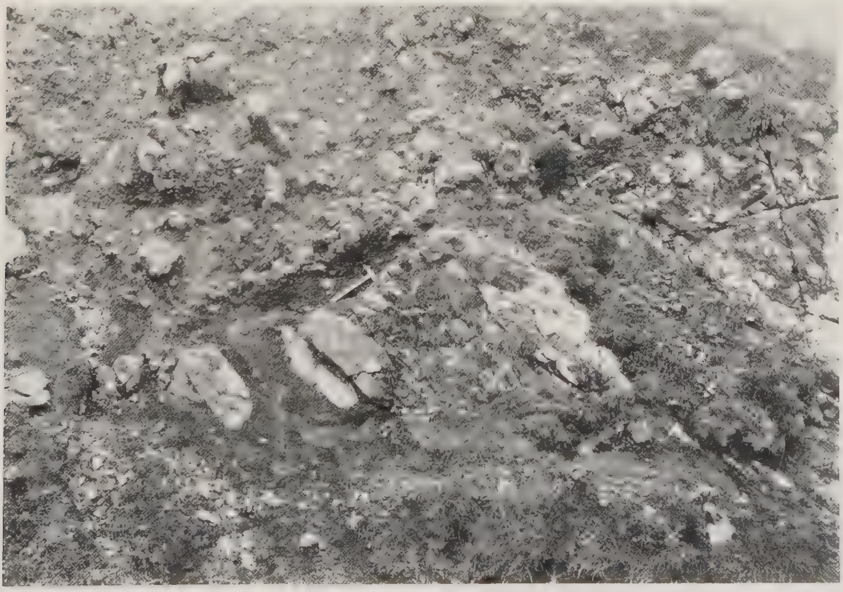

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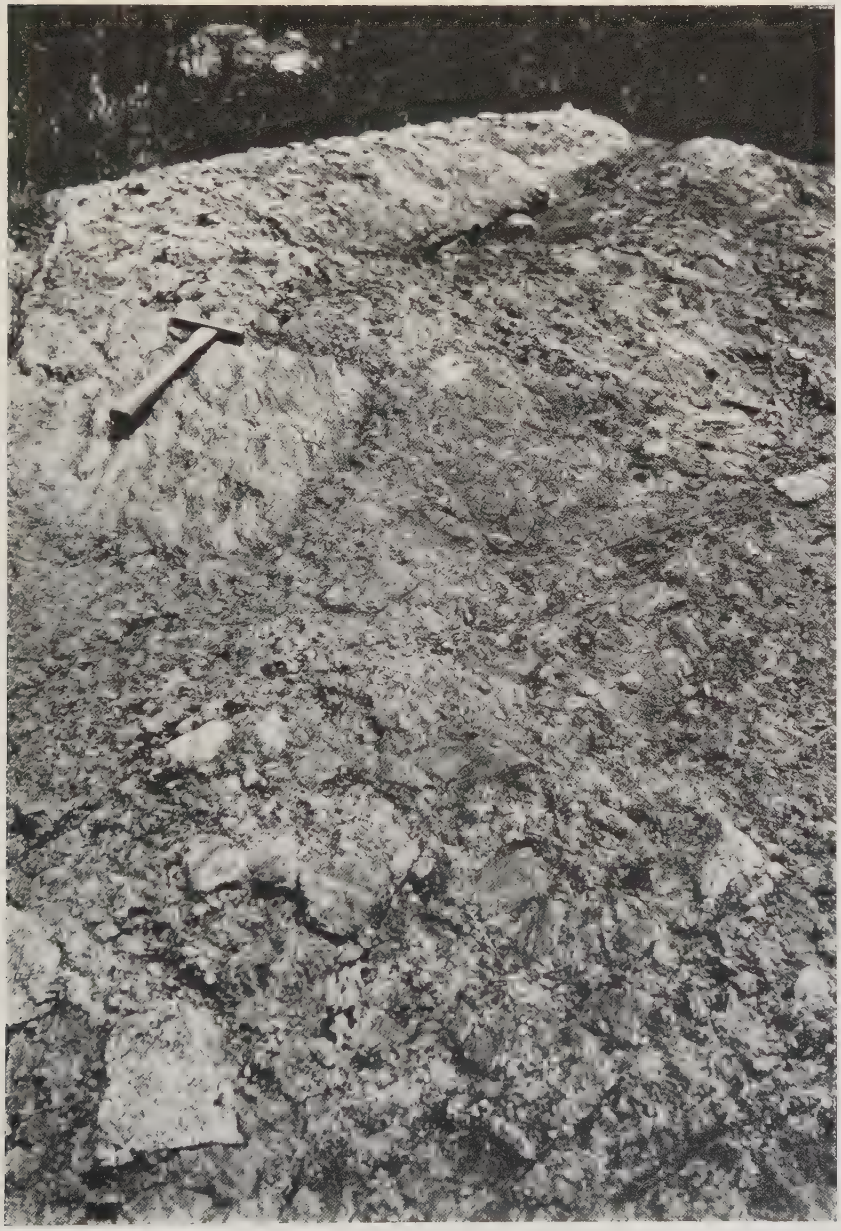
Fig. 2. — Inclined edge of the earlier vent of Ben Hiant. The vent-agglomerate cuts across ong the junction indicated by the hammers) an earlier dyke which is intrusive in the plateau salt lavas.

PL. III.

Richey. — *Explosive brecciation and plutonic intrusion,*
British Tertiary igneous province.



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AGGLOMERATE BELONGING TO THE EARLIER VENTS, FROM BEINN BHEARNACH, ISLAND OF MULL.

The ingredients are composed of various rock-types, including many of non-volcanic origin. r example, the hammer rests on a large block of Moine schist or gneiss, and fragments near ttom of photograph are Tertiary granophyre.

Dr. E. B. BAILEY, F. R. S.

Report on British Vulcanological Research during the period September 1936 - August 1939

In order to render this report more comprehensive, reference is made to researches carried out in British Colonies as well as in Britain itself, and in addition the more important papers dealing with vulcanological subjects in other countries which have been published during the triennial period in England are included in the Bibliography.

Since active volcanoes within British territory are so few, it may not be out of place also to draw attention here to the ash eruptions from two volcanoes, Vulcan and Merapi, in the harbour of Rabaul in New Britain (under Australian mandate) in May-June 1937 (20) and from Mount Bagana on the neighbouring island of Bourgainville in July of the same year.

A note on the Vulcanological Observatory at present being built at Rabaul has been kindly supplied by Dr. N. H. Fisher for transmission to the Washington Assembly (p. 185).

Montserrat, British West Indies. — Earthquakes and abnormal soufrière activity, previously experienced in the island between 1897 and 1899, were renewed in Montserrat between 1933 and 1936. The abnormal conditions were first studied by Mr. F. A. Perret, of the St. Pierre Volcano Museum, in 1934 and 1935. In 1936, under the joint auspices of the Royal Society and the Colonial Office, Dr. C. F. Powell and Dr. A. G. MacGregor were sent out to study and report on the seismic and volcanic phenomena, and to carry out a geological survey of the island. Dr. MacGregor' s results (13) may be summarised as follows, under three headings.

Volcanic History of Montserrat. — The island was shown to consist of seven contiguous volcanoes arranged along two intersecting lines. Several of the younger centres were proved to be not older than the Pleistocene. The most recent volcano was found to have a summit resembling that of Montagne Pelée, and to have been characterized by eruptions of *nuée ardente* type. Seven active soufrières on the slopes of this volcano were located, and their activity is discussed in relation to the seismic evidence of Mr. PERRET and Dr. POWELL. Seismic and soufrière activity are clearly interrelated. Soufrières appear to be localized, like the volcanoes, along lines of deep-seated crustal weakness traversing the island. A renewal of violent explosive activity is not anticipated.

Seismo-volcanic Activity in the Caribbean Volcanic Arc. — It is suggested that the main volcanic activity of the Caribbean arc was connected with Miocene and Pliocene earth movements, the series of events corresponding to those of the Cascadian Revolution of western North America. Deductions regarding the probable time and location of future seismo-volcanic disturbances in the Lesser Antilles are drawn from the records of seismic, soufrière and volcanic activity in Montserrat and other islands. It is shown by means of a graphical chart that in historic times the main centre of disturbance has tended to oscillate back and forth along that part of the volcanic arc between St Kitts and St. Vincent.

Petrology. — Detailed petrographic study of the rocks of Montserrat shows that they cover most of the range of types in the Lesser Antilles, and resemble closely many of those known in the Lassen Peak district of California. New evidence is presented bearing on the mode of formation of Peléean volcanic domes, on the mechanism of *nuées ardentes*, and on the formation of breadcrust bombs of Peléean type. Tridymite and cristobalite were found to be very prevalent in Montserrat, and cristobalite (as such) is recorded for the first time in the rocks and volcanic dusts of Montagne Pelée. Other subjects dealt with in connection with the bandaites (labradorite-dacites) of Montserrat are the origin of semi-glassy cognate inclusions and the magmatic alteration of hornblende.

Central Africa. — An account of the extinct volcano of Katunga in South-west Uganda is included in a memoir (5) and papers by Dr. A. D. Combe (4) and Prof. A. Holmes (6). Of particular interest is the recognition of lava flows composed of potash-rich olivine-melilitite (katungite), the first record in this area (Ankole and Toro). Holmes (8) discusses at length the hypothesis of the formation of magmas by the action of emissions from ultrabasic magmas upon sedimentary rocks.

Alkaline volcanic rocks from Kenya supply material for petrographical studies. In lavas and tuffs from the Turkana district, to the west of Lake Rudolf, Lt. Col. W. C. Smith (19) has demonstrated a wide range in composition, though rhyolitic and basaltic types are dominant. In the Kedong scarp, Kenya Rift Valley, lavas and tuffs previously described by Prof. S. J. Shand (1936), are further dealt with by the same author (18) and include trachytes and olivine-basalt. It is suggested that felsparphyric basalt and ‘augitite’ may have been derived from the same magma by flotation of plagioclase crystals and concurrent sinking of augite and hornblende.

Britain. — Bedded pyroclastic deposits of Lower Ordovician age, with high content of soda, in the Welsh Borderland (Shrosphire) and, together with lavas, in the North of England have been investigated respectively by Mr. F. G. H. Blyth (3) and Prof. S. N. Hudson (9). Interbanding with argillaceous, graptoliferous sediments discloses the submarine origin of the eruptions and, in Shropshire, individual pyroclastic beds are regarded as the products of separate outbursts. Their wide variation in texture has led Mr. Blyth to suggest a classification based upon the sizes of the majority of the particles or fragments. Tuffs from the North of England contain, among a variety of other ingredients, glassy spilitic fragments and palagonitic andesitic glass.

Interbedded tuffs and mainly trachytic agglomerates, infilling Tertiary vents in Ardnamurchan, Scotland, are considered by Dr. J. E. RICHEY (16) to indicate a rhythmic series of eruptions, each of which began with an agglomerate phase and ended with a strong gas phase forming fine and dust tuffs. From the same district, too, Dr. Ph. H. KUENEN (12) has collected new field observations concerning cone-sheets, which support the theory that their injection was accompanied by the vertical lifting of the upper wall.

Of interest for the student of ring tectonics is a paper by Dr. J. G. C. ANDERSON (1) dealing with a complex of granitic ring-dykes of Devonian (Caledonian) age in the neighbourhood of and later than the classic lava-intrusion cauldron of Glen Coe, Scotland.

Studies bearing upon the fundamental problem of the origin of magmas are certainly the concern of the volcanologist as well as the petrologist. Dr. R. W. van BEMMELEN (2) has advanced his Undation Theory with examples, mainly Tertiary, drawn from Scotland. Drs. W. Q. KENNEDY and E. M. ANDERSON (10) have approached the problem from the point of view of earth magmas and crustal layers. A controversy concerning the differentiated Tertiary ring-dyke of Glen More, Mull, has been continued by Drs. KOOMANS and KUENEN (11). Objections are offered to the explanation of the intermediate types by hybridization, and the authors in general agree with the original interpretation of CLOUGH, THOMAS and BAILEY that the gradual transition observed from basic to acid materials was effected *in situ* before the final consolidation of a single body of magma. On the other hand, the formation of distinctive rock-types by reactions between sedimentary rocks and magmas or their emanations has been advocated by Dr. Malcolm MACGREGOR (14) in the case of one of the Scottish Caledonian plutonic masses, and, from a different standpoint, by Dr. D. REYNOLDS (15) and Prof. A. HOLMES (7) in regard to the transfusion of quartzite (Colonsay) and quartz xenoliths (Uganda). In a paper dealing with the dykes of Scotland by Dr. J. E. RICHEY (17), many facts will be found which also have some bearing upon the derivation of the intrusive magmas.

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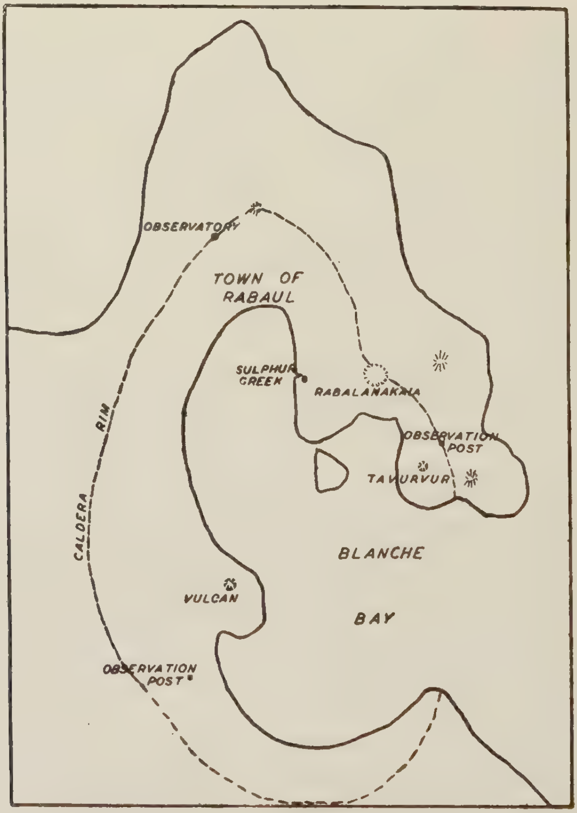
N. H. FISHER
DEPARTMENT OF LANDS AND MINES, RABAUL

Note on the Vulcanological Observatory at Rabaul

« The main Vulcanological Observatory at Rabaul is being built on the northern rim of the Blanche Bay caldera, about 600 feet above sea-level. The site overlooks Blanche Bay and the town of Rabaul, and commands an excellent view of the two volcanoes Tavurvur and Raluan (Vulcan), also of the older craters (probably extinct) Rabalanakaia and Sulphur Creek. The Observatory will consist of an insulated cellar 25 × 15 feet for the housing of instruments, over which will be built an office, laboratory, dark room, observation room and a small museum. A two component horizontal and a vertical Wiechert seismograph are being installed, both with a heavy mass of 80 kilograms. Two tiltmeters of an Italian model will measure the north-south and east-west components of any tilts that may affect the site. Other necessary instruments, radio receiver, contact clock earthquake annunciator, thermometers, cameras, microscope, gas analysis apparatus, gas masks, a grinding lap for making thin sections, telescope, binoculars, etc. will be included in the equipment.

« In addition to the central observatory, observation posts will be established near each of the craters, Raluan and Tavurvur. Both of these will consist of tunnels, driven into the old caldera wall opposite the volcanoes, fitted with gas proof doors, and connected by telephone with the main observatory. Small two component tromometers will be installed in each post, and two component tiltmeters. At both of these posts and at the central station meteorological observations will be taken daily.

« The work of the station will consist of the recording and study of all tremors registered, both at the main station and at the observation posts, and the sending out of monthly seismological bulletins. Temperatures, at a great number of fixed points, of hot springs, fumaroles and solfataras, and ground temperatures, will be taken, in many cases daily, instead of weekly as previously. Analyses of solfatara gases will be made at regular intervals. Tilts, ground subsidence or elevation will be measured by the tiltmeters, by levelling fixed points at intervals and by tide gauges. Field mapping and petrological research will be carried out as opportunities offer, and visits will



be made from time to time to active volcanoes of the Mandated Territory. Cooperation of persons residing near volcanoes will be sought and all possible information regarding eruptions and the state of activity of the volcanoes will be collected. It is hoped later to build further tromometers and install them at other places in the Territory.

« The Observatory is now under construction and the instruments have been on order for some time, so it is probable that the station will be in operation before the end of the current year. The accompanying sketch plan shows the position of the Observatory and the town of Rabaul, and the volcanoes and observation posts ».

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Notes on Fluorine

(With 1 text-figure)

It is a well-established rule that the beginning or the renewal of active volcanism is accompanied by the appearance or the dominance of the halogens, whereas the decline and extinction have sulfur dominant. The application of this rule calls for the usual discretion because the concentration of halogens differs at different volcanoes. At Kilauea, for example, chlorine is present in very low concentrations, and most of the writer's tests of the gases around Halemaumau were negative and the incrustations show no more chlorine than would be expected in any terrain. Other volcanoes, and especially the more acid types of lavas, show quite different results, and large amounts of chlorides or hydrochloric acid may be present.

Little or nothing is known of that other important halogen, fluorine. Fluorides have been reported from time to time and ZIES has reported enormous amounts of hydrofluoric acid being given off in the Valley of Ten Thousand Smokes. We are equally ignorant of the quantity of fluorine present in rocks. CLARKE, in his *Data of Geochemistry*, estimates from scanty data that it should be about one-third the concentration of chlorine. Rock analysts have consistently and wisely refused to determine it for lack of any acceptable method. This situation was remedied with the publication in 1933 of WILLARD and WINTER's method for determining fluorine, and since then there has appeared a rapidly growing literature mostly concerned with the fluorine content of waters.

It seemed desirable, therefore, to make at least a reconnaissance of the fluorine content of rocks and lavas, and these notes supply our first data. The figures have been roughly grouped in the order of silica content with some separation according to geographical location. The figures are set forth in Table I.

TABLE I

Fluorine Concentration in Various Rocks

No.	Eruptives		% F
1	Obsidian, Coso Mts., Calif.	(Cl = 0.08 %)	0.121
2	Obsidian, Coso Mts. (not same as No. 1)		0.095
3	Obsidian, Coso Mts. (glass surrounding spherulite).		0.094
4	Crystalline kernel of No. 3		0.078
5	Obsidian, Newberry Volcano, Oregon (No 75, HLW)		0.064
6	Obsidian, Mono Lake, Calif.	(Cl = 0.13 %)	0.062
7	Obsidian, Mt. Morrison Area, Calif.	(Cl = 0.11 %)	0.064
8	Little Glass Mt., Calif. (dense glass)	(Cl = 0.03 %)	0.049
9	Little Glass Mt., Calif., Type 2	(Cl = 0.08 %)	0.054
10	Little Glass Mt., Calif., Type 3, more vesicles	(Cl = 0.09 %)	0.050
11	Little Glass Mt., Calif., Type 4[a]	(Cl = 0.09 %)	0.048
11[a]	Little Glass Mt., Calif., Type 4		0.047
12	Little Glass Mt., Calif., Type 5	(Cl = 0.07 %)	0.034
13	Little Glass Mt., Calif., Type 6, pumice	(Cl = 0.07 %)	0.035
14	Black glass, Cerro Noagua, New Mexico	(Cl = 0.06 %)	0.062
15	White pitchstone, Cerro Noagua	(Cl = 0.08 %)	0.152
		Average	0.070
	Lava Flows		
16	New Cone, No. 6, Mt. Pelée, Martinique	(Cl = 0.02 %)	0.008
17	Breadcrust, No. 7, Mt. Pelée, Martinique	(Cl = 0.09 %)	0.009
18	Spine, 1902, No. 5, Mt. Pelée, Martinique.	(Cl = 0.02 %)	0.008
19	Mauna Loa, summit spatters, 1926	(Cl = 0.01 %)	0.007
20	Mauna Loa, 1926 flow, 7500′ elevation	(Cl = 0.01 %)	0.009
21	Mt. Erebus, Antarctica, edge of crater, 1908		0.064
22	Lassen Peak, Calif., No. 35		0.023
23	Lassen Peak, Calif., No. 21		0.009
24	Cinder Cone, quartz basalt		0.008
		Average	0.010

Italian Group

25	Aetna, 1910 flow	0.063
26	Aetna, 1669 flow	0.035
27	Obsidian, Lipari.	0.096
28	Stromboli, 1912	0.036
	Average	0.057

29	Iceland, dike selvage, Hawkes No. 391	0.156
30	Iceland, altered dike, Hawkes No. 238	0.338

African Rift Area, N. L. Bowen

31	No. 253	0.065
32	No. 231.	0.141
33	Obsidian, Naivasha	0.685
34	Selvage No. 116.	0.204
35	No. 117.	0.028
36	Leucite nephrite, No. 120, N. Kivu	0.159
37	Entrance Njarowa Gorge, No. 246	0.414
38	1 km. inside Njarowa Gorge, No. 247.	0.279
39	Glass from Eburra, No. 230	0.172
40	No. 248.	0.280
41	Quartz trachyte, No. 234.	0.225
42	Phonolite, No. 243	0.088
43	Phonolite trachyte, No. 303	0.113
44	Phonolite, No. 235	0.103
45	Phonolite pitchstone	0.149
	Average	0.207

Katmai Area, C. N. Fenner's Collection

46	Rhyolite, altered old rock, Novarupta	0.017
47	Much altered old rock, A-415.	0.015
48	Altered basic inclusion, A-380	0.061
49	Old rock, Falling Mt., corroded by fumaroles	0.007
50	Basic inclusion, Novarupta, A-383	0.010
	Average	0.021

Yellowstone Park, Fenner

51	Basalt-rhyolite mixture, No. 537	0.035
52	Basalt-rhyolite mixture, No. 415	0.022
53	Rhyolite, vesicles with tridymite	0.012
	Average	0.023

54	Crystalline striae, Obsidian Cliff		0.122
55	Glass between striae of No. 54	(Cl = 0.05 %)	0.152
		Average	0.137

Miscellaneous Rocks and Plutonics

56	Biotite (NLB)		0.214
57	Grünerite, Lockport, N. Y. (NLB)		0.010
58	Hedenbergite		0.000
59	Serpentine, Oregon		0.012
60	Granite, Stone Mt., Georgia	(Cl = 0.03 %)	0.039
61	Marvine laccolite, Henry Mts., Utah	(Cl = 0.02 %)	0.062
62	Baked shale adjacent to No. 61		0.029
	Shonkin Sag, Montana:		
63	Shonkinite		0.141
64	Syenite		0.227
65	Coarse transition phase		0.178
66	Shonkinite, dark portion		0.206
67	Shonkinite, light portion		0.054
68	Adinole from beneath the laccolite		0.021
69	Sedimentary splinter caught up into the mass		0.233
70	Basic inclusion, S. Bernardino Mt., Calif.		0.029
71	Diabase, Granton, New Jersey	(Cl = 0.03 %)	0.026
72	Basalt flow, Mt. Morrison Quadrangle, Calif.	(Cl = 0.01, P_2O_5 = 0.80 %)	0.106

Sedimentaries

73	Slate, Rochester, New York		0.109
74	Fossiliferous limestone, Maryland		0.023
74^a	Fossiliferous limestone, Maryland.		0.021
75	Arenaceous shale, New York		0.024
76	Calcareous shale, New York		0.025
77	Shale, Maryland.		0.033
78	Argillaceous limestone		0.037
		Average	0.027

For our present purpose it will suffice to emphasize only the average fluorine content of the various groups.

The obsidians constituting the first group are all good black glasses with none or rare phenocrysts. They come from the western United States, contain more than 70 %

SiO_2 and varying amounts of water, usually low. The fluorine content averages 0.07 % with a marked tendency towards 0.1 %. A similar black glass in Bowen's African collection shows 0.685 % F, the highest concentration yet encountered. This glass was from a very large flow and not an alteration product.

Fresh lavas were disappointing, showing an average content of about 0.01 %, with a few understandable exceptions. But here the figures may well be deceptive. For example, Numbers 46 to 50 in Table I are pumiceous rhyolites from the Valley of Ten Thousand Smokes, where Zies observed that enormous quantities of fluorine had either been evolved from, or had passed through, these rocks, although the fluorine retained by the rock was only about 0.02 %. It seems possible, therefore, that the low fluorine content of the lavas tested may be due more to the mobility of this elusive element than to the poverty of the magmas. This point is much in need of careful checking by those who have opportunity to do so in the field.

There is some evidence for suspecting regional concentrations of fluorine. For example, the lavas from Martinique, California, and Hawaii approach only 0.01 %. The few specimens from Italy average 0.057 % and if we omit the Lipari obsidian with its 0.096 % the concentration is still 0.044 %. Two Icelandic specimens, a selvage and an altered dike (Nos. 29 and 30), contain several tenths of a percent. Bowen's series from the African Rift area averages 0.2 % F, a figure reached only by some obsidians and the shonkinite-syenite group from Montana. The analyses are too few and too selected to permit more than an indication.

Until sufficient data are available to warrant generalizations we may assume that the figures for our « standard » rocks are normal values. Thus we selected a granite from Stone Mountain, Georgia, which petrologists regard as typical, free from alteration and of average composition [1]). For this we find Cl = 0.03 % and F = 0.039 %. The diabase from Granton, New Jersey, shows Cl=0.03 % and F = 0.026 %. If these rocks are typical, as we believe them to be, then instead of being present in unimportant amounts fluorine is present in amounts equal to or greater than chlorine in the earth's crust. This obviously poses the question as to what becomes of this fluorine during the wearing down of the rocks by weathering.

For comparison we have included a few sedimentary rocks which yield about 0.02 % F and compare with the ocean-bottom specimens shown in Table II.

TABLE II

Ocean - Bottom Samples

Collected by the CARNEGIE

CARNEGIE Station	Type of sediment	% F
6	terrigenous	0.053
43	globigerina ooze	0.028
44	globigerina ooze	0.033
51	globigerina ooze	0.054
60	globigerina ooze	0.035
62	globigerina ooze	0.033
67	globigerina ooze	0.032
113	terrigenous	0.029
116	terrigenous	0.020
117	red clay	0.033
119	diatom-terrigenous	0.032
127	blue mud	0.072
131	red clay	0.071

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[1] Our selection of the Stone Mountain granite as typical has been criticized on the ground that the mass is shot through with veins which contain tourmaline, etc. The block which we have used as a standard is not only normal but free from alteration. The criticism is sound if we can find other normal granites free from such pegmatites and from alteration. At this time we use the Stone Mountain granite as a norm until the work shall have gone far enough to include many other granites. We let the figure stand until we are in position to reach a definite average value. Several other granites have been suggested but thus far all have failed to meet the standard in one detail or another.

132	red clay	0.069
133	red clay	0.071
136	red clay	0.086
137	red clay	0.033
151	red clay	0.114
156	red clay	0.050
157	globigerina ooze	0.010
160	globigerina ooze	0.038
	Average	0.047

From C. S. Piggot's Collection, Atlantic Ocean

N 39° 13′ W 72° top of core	0.109
Bottom of core, 62″ below top	0.038
Hudson, No. 3	0.035
N 38° 10′ W 73° 50′	0.047
N 37° 26′ W 74° 28′ Maryland Canyon, 700 fathoms	0.039
N 37° 26′ W 74° 28′ Maryland Canyon, 228 fathoms	0.025
Average	0.048

From T. G. Thompson's Alaskan Collection

B 14683	0.037
B 14684	0.023
B 14685	0.028
B 14686	0.038
B 14688	0.044
B 14690	0.021
B 14691	0.056

The Alaskan group was supplied by Dr. Horace G. Byers of the Bureau of Chemistry and Soils, U. S. Department of Agriculture. All consisted largely of volcanic ash.

The average of all ocean-bottom samples is 0.043 % F.

With the exception of No. 6, the first group is from the Pacific Ocean, collected by the Carnegie, and we thank Dr. Fleming for the opportunity to study it. The Atlantic series we owe to Dr. C. S. Piggot, and the Aleutian series was provided by Dr. Horace G. Byers of the Bureau of Chemistry and Soils, U. S. Department of Agriculture, and comes from Dr. T. G. Thompson's collection.

It will be noted that the globigerina ooze tends to be much lower in fluorine content than the clays and that the average for this series is 0.047 % fluorine. The Atlantic specimens average 0.048 % F, while the Aleutian specimens, which are largely volcanic ash, average only 0.035% F. The geographical distribution is shown in Fig. 1, in which

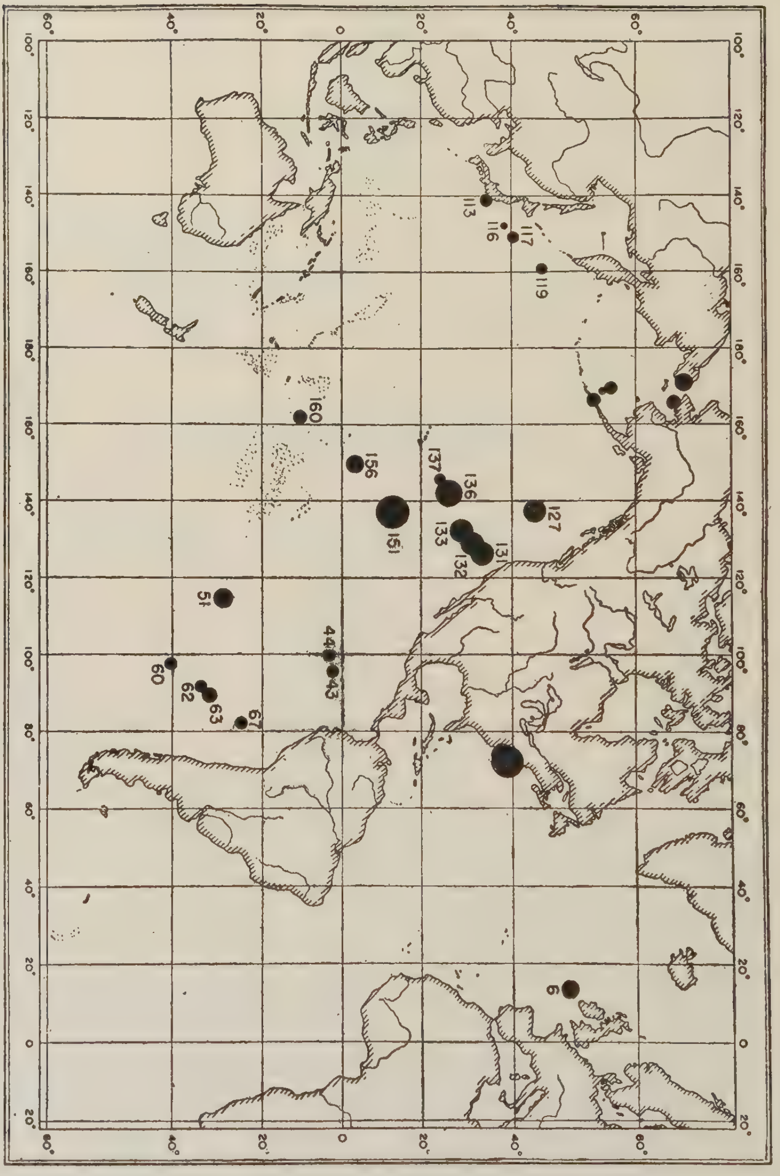

Fig. 1.—Fluorine content of ocean-bottom samples. Fluorine concentration proportional to diameter of circles. Numbers refer to Carnegie stations.

the diameter of the circles is proportional to the fluorine concentration, with the largest circles about 0.10 %.

The Pacific series is interesting. The Japanese current, which sweeps past Japan, crosses south of the Aleutian Islands, follows down the west coast of North America and then turns westward again as the North Equatorial current. In view of Zies' observations at Katmai and the age-long activity of the Japanese volcanoes one would have expected a maximum all around this circuit, whereas the fluorine concentration is normal or lower until the current bends back westward. The maximum concentration is laid down between Lower California and Hawaii. No explanation can be regarded as other than suggestive and H. E. Merwin calls attention to the fact that in the weathering of coastal rocks the very fine particles of muscovite sink so slowly that they may be an important factor in determining the fluorine content of the bottom.

Conclusion

1. Instead of being present in trifling amounts, fluorine is evidently present in amounts equal to or greater than chlorine.

2. It is a reasonable inference that the average content of the igneous rocks is about three to four hundredths of a percent. The average content for all specimens analyzed is 0.064 % but this figure is invalidated by the fewness of the analyses and the too great selection of the specimens studied.

3. We find that the fluorine retained in lavas is not too reliable an index of the amount which may have been present at the time of eruption. We are as yet ignorant of the particular indications of the former presence of this elusive element; the trail is still blind.

4. Now that an easy and accurate method for its determination is available fluorine must be included among the elements which the volcanologist is watching. There is

as yet no simple, easy field test, although one can readily be devised. The collection of gases in such a manner that fluorine can be determined quantitatively offers difficulties but not serious ones.

The known effect of fluorine on the viscosity of silicate melts and as a mineralizer now comes into the range of the volcanologist's vision as a factor to be studied.

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Volcanoes in the Mariana Islands in the Japanese Mandated South Seas.

(With 9 fig. and 8 plates)

Foreword

In the summer of 1936, through the courtesy of the Imperial Academy of Japan, the writer visited the islands of the Mariana Archipelago to study some of the volcanoes there. There is a regular steamer service from Yokohama to Saipan, the main island of the Group, from which a small mail boat makes four annual trips northward to Agrigan island, stopping at every inhabited island en route. Taking a small boat (about 7 tons) from Pagan, I proceeded northward to the uninhabited islands of Uracas, Maug, and Assongsong.

Being uninhabited islands, the writer and his assistants encountered numerous difficulties in obtaining information and carrying out investigations, so that the results are not so complete as we had desired.

The following is only a general sketch of the volcanoes in the Mariana Archipelago. The maps referred to here are those that were constructed from the Japanese Imperial charts and published 1) by Prof. TAYAMA, of the Geological Institute of this University. The rock determinations and most of the analyses were made by Dr. H. TSUYA of the Earthquake Research Institution, while some

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1) R. TAYAMA: *The topography, geology, and coral reefs of the northern part of the Mariana Islands.* Report (Japanese) of the Institute of Geology and Palaeontology, Tôhoku Imperial University N°. 23, 1936.

of the analyses of rock specimens were made at the Imperial Japanese Geological Survey under the direction of Dr. S. YAMANE. I record here my great indebtedness to these gentlemen.

The Mariana Islands and the Submarine Topography of their environs

The arcuate chain of volcanoes in the Mariana Archipelago seems to be a continuation of the southern end of the Japanese Huzi (or Fuji) volcanic zone, although it is interrupted in the south of the Iôzima Islands (Volcano Islands) by about 550 km of water. Mt. Huzi, 3,778 m, stands in the central part of Honsyû, in the great tectonic depression called *Fossa Magna* by some authors. This Huzi volcanic zone, which originates here, stretching for about 1,400 km, S. S. E. into the Pacific ocean in the direction perpendicular to the trend of the main arc of the Circum Pacific fold, contains the volcanoes of Izu Peninsula and two chains of island volcanoes, Sititô and Iôzima, and finally reaches the Mariana volcanic island.

If we examine the submarine topography south of Japan, we find that the main ridge of this zone rises from a depth of more than 4,000 m, and extends straight southward, dividing the Japan trough in the west from the southern extremity of the Tuscarora deep with a maximum depth of more than 10,000 m in the east. This main ridge contains three culminations above a depth of 3,000 m, namely, the Sititô, the Iôzima, and the West Mariana islands, of which the last-named has no island volcanoes, as will be mentioned later. In order to have a clear understanding of the foundations of these volcanoes, it is necessary to have details of the submarine topography of the southern extremity of the Iôzima Islands as well as those of the Mariana Islands. At the southern extremity of the Iôzima Islands, the main ridge divides into two parts (both have their sides convex towards the east). These two ridges are the Western Mariana Ridge and Eastern Mariana Ridge or, in Prof. TAYAMA's words, First Mariana Ridge and Second Mariana Ridge.

The western ridge rises from a depth of about 4,000 m to a height of about 1,500 m, its width at its base being 130 km. It is 1,400 km long, with several smaller submarine ridges and domes rising from it, although none of them reaches sea level. The Eastern Mariana ridge rises about 2,000 m from a depth of about 4,000 m in the western base, while its eastern foot is the bottom of the Mariana trench, more than 9,000 m deep, and of which the deepest part is known as the " Nero deep ,, (9,636 m). For a clear idea of the geological relationship of the Mariana Archipelago to this submarine ridge, it is necessary to examine the northern extremity of the Iôzima Islands. Parallel to the east of the Iôzima Islands, there is a branch of the submarine ridge called the Bonins, comprising a number of islands that consist of sedimentary layers of Tertiary age and some volcanic rocks. Although the southern continuation of the Bonin Islands is not discernible, even from its submarine topography, similar characteristics occur as in the case of the Marianas. From the southern end of this arcuate ridge rise two parallel chains of islands, the outer or eastern chain, called here the Saipan chain, for convenience, comprising such islands as Saipan, Tenian, Rota, Guam, etc., built up of sedimentary rocks of varying periods, older volcanic rocks, and of recently raised coral reefs, like Bonin islands. The inner, or the western ridge, is a continuation of the Iôzima Islands, called here the Uracas chain, from the name of the most typical conide on it. These two chains run parallel for a distance of 50 km, while in the case of the Bonins the distance between the two chains is about 150 km.

The Mariana volcanic islands, or the Uracas chain, contains many island volcanoes and submarine reefs. The volcanoes are Uracas, Maug, Assongsong, Agrigan, Pagan, Alamagan, Guguan, Sarigan, Anatahan, in addition to which there are the Supply reef, the banks of Sealandia and Esmeralda. All these are mentioned in detail in the Appendix.

Descriptions of the Island Volcanoes

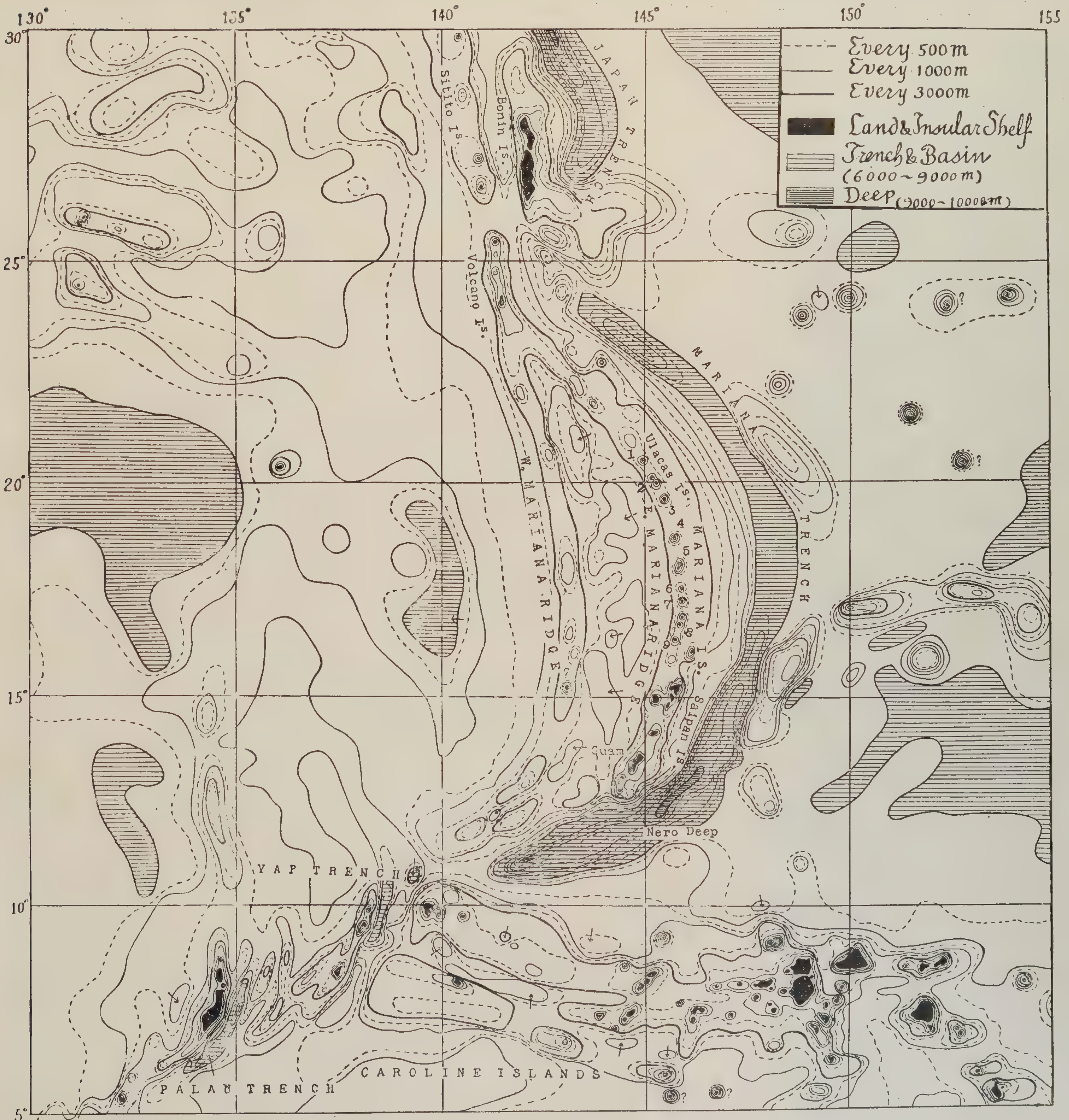
1. — Uracas Island

Description : This volcano is a typical conide of andesitic rocks, with a height of 319 m a. s. l. (above sea level). It is the central cone of a caldera whose wall remains as small hills culminating at a height of 144 m a. s. l. on the southern side of the island. Judging from the submarine topography of the island and the structure of the caldera wall, the somma volcano was probably a gigantic mass with a height exceeding 2,000 m from the sea bottom. The crater is situated westward from the center of the island, so that the western side is very steep with an inclination of 30°, resembling the *Sciara del Fuoco of Stromboli*. The crater, which is constantly emitting sulphurous gas, is 60-65 m in diameter, with a nearly vertical inner wall. It's rim is almost of the same height ; the western part being somewhat lower than the rest.

The northern flank was the scene of lava-flows in recent years. According to many observers, an incandescent liquid mass was descending through fresh lava canals down to the foot of the volcano and thence into the sea.

Towards the east and south, the average slope of the flank is 25°, and at a level of 80 m a. s. l., a number of lava streams flowed from the flank , penetrating the thick wall of the volcanic vent. In places, the thickness of the outflowing lava was as much as 20 m and more, the fluidal mass, not having consolidated yet in its middle part of, issues from the end, forming a secondary stream. Excepting on the western side, the piano of the volcano forms a vast field of slaggy lava of a-a type, which had issued from time to time from the flank of the cone as well as from the crater. On the sea cliff of the southern side of island, three different layers of such lava could be distinguished.

Submarine Topography of the Environs of the Mariana Islands.



By Tayama & Tanakadate

Fig. 1.

Of the above mentioned characteristics, the asymmetry of the form of the island, just mentioned, might have been caused by unequal subsidence of the sea bottom, which was a sort of tilting towards the west. The various eruptive manifestations of this volcano serve to show that lava displays various eruptive features according to its physical conditions. To illustrate, if at the time of eruption, the lava in the volcanic vent has a very high temperature, the activity is of Strombolian type, whereas in the case of the contrary, the eruption is of Vesuvian or Sakurazima type, sending out enormous quantities of lava of a-a type. The difference in the temperature of the lava might sometimes depend on the ascending rate of the lava in the volcanic vent from the eruption.

Activity : Uracas volcano, by its almost constant eruption of Strombolian type, acts as a light-house for the Mariana Archipelago. According to the history of this volcano, it was active in 1865, and again in 1875, with explosive eruptions. In 1901 and 1902 it was also active issuing smoke intermittently. In 1912, the activity was particularly violent, and in 1925, a strong Strombolian eruption was seen. In recent times, the activity has consisted of very violent paroxysmus, with emissions of scoriae, which explains the fire phenomena at night.

According to Prof. TAYAMA, in September-October 1932, the volcano showed intermittently paroxysms every ten to twenty minutes. Following violent detonations, smoke columns rise up to heights of 150 m above the crater, hurling large blocks of red hot lava and lapilli into the sky, shortly after which liquid lava overflows the crater rim on the flank of the volcano into lava canals and find their way into the sea. At night, the incandescent lava could be seen streaming from the crater and dividing into three branches at the lower part, all of them reaching the sea.

For several months, in 1934, this volcano was quiescent. In the spring of 1936, reports were received of the Strombolian activity of this volcano, but when the writer visited it in the summer of that year, the explosive eruptions were no more to be seen, slight sulphur fumes being all that could be seen issuing from the crater. This year it is manifesting again its characteristic eruptions.

Petrography : The lava on the caldera relics of the island consists of four different layers, the lowest of which is an olivine-bearing two-pyroxene-andesite, while the lavas of the two middle ones are two pyroxene-andesite containing no olivine.

There are several different layers of new lava of a-a type, which are mostly very slaggy. After carefully examining a large number of specimens they have been classified as two-pyroxene-andesites. The reddish lava forming a vast field with very rough surface at the northwestern foot of the cone is an olivine-bearing-augite-andesite.

Submarine eruption : According to the inhabitants of Saipan island, in the summer of 1934, a submarine eruption occurred in the vicinity of Uracas (20° 31′ N, 144° 53′ E) when large quantities of steam were seen rising from the sea. In the neighbourhood of which there floated enormous quantities of pumice of a dark color.

2. — **Maug Island**

Description : This is a caldera volcano like Santorin in the Mediterranean Sea, and consists of three islands, each of which is a part of the caldera wall. The northern most island of the three is 228 m a. s. l., the steep inner wall has an average inclination of 40° while the outer slope has one of 25°. On the inner wall may be seen more than 10 layers of lava, pierced by many dykes trending in a NE direction.

The western island, 180 m. a. s. l., is arched, with a length of 2,4 km, its slope inclining 50° toward the inner side and 25°-30° towards the outer side. In the southern part of the inner wall, steep precipices of terminal facets stand directly above the deep water.

The eastern island, of triangular shape, is the largest of the three. The inner wall is steep, about 60°, while the outer wall averages 20°. Steep precipices of terminal facets as high as 100 m are found in the some places of the inner wall, while wave cut cliffs 50 m high border the eastern coast. About ten lava streams of different thicknesses have been counted on the inner wall.

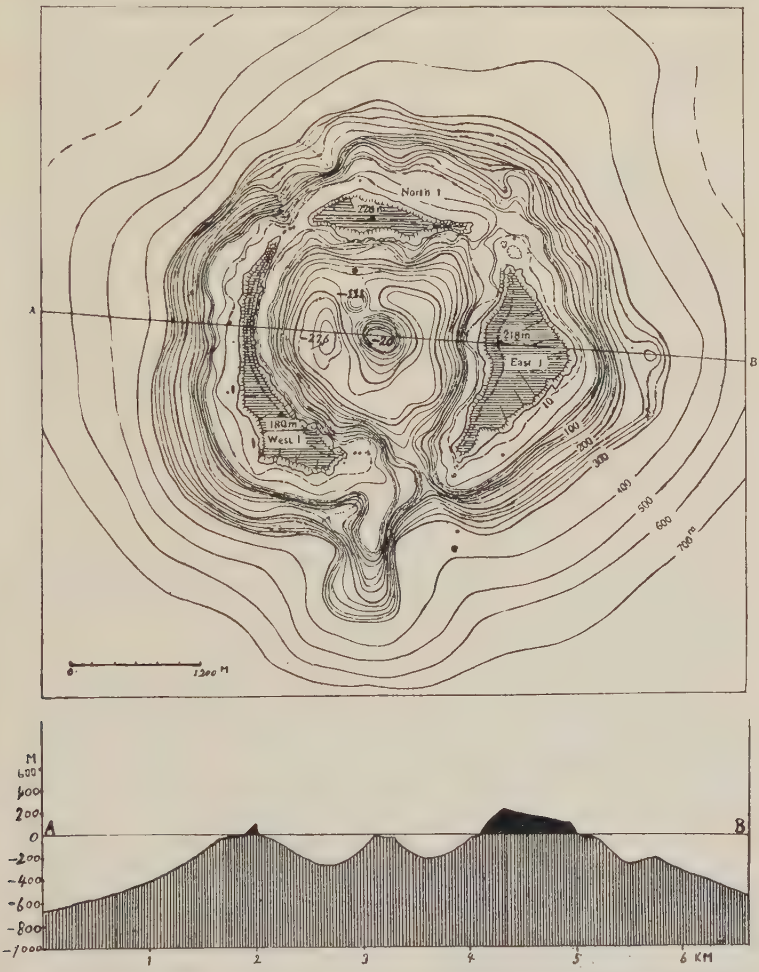


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Fig. 2. — **Maug Island**

An isobathymetric line of a depth of 30 m encircles the above three islands, excepting the southern canal, which is 150 m deep, and embraces a circular bay having a diameter of 2 km. The bottom floor, which is deeper than 220 m, is U shaped, with its opening toward the northwest.

The central volcano of this caldera is a submarine dome standing on the sea floor at a depth of 276 m below sea level, from which it rises 256 m and reaches a depth of 20 m below sea level. The diameter of the top surface is about 200 m and that of the base 600 m, so that the slope is more than 45°. Near the northeast of this dome, there is another small dome whose height is about 80 m above its base, so that its top is at a depth of 111 m below the sea.

The two submarine domes just mentioned stand on a zone that passes through the southern canal and is believed to be a fissure trending NNW.

This volcano is a good example of a caldera that was formed mainly by depression followed by a reactive eruption usually resulting in domes.

Petrography : In the northern island, the lower layers of lava forming the inner wall are an olivine-basalt, while the upper layers, intercalated by thick scoria of various colours, are augite-bearing-olivine-basalt. Several of the dyke rocks were found to be an olivine-basalt.

In the eastern and western islands, we find augite-andesites and two-pyroxene-andesites. Prof. TAYAMA found an olivine-augite-andesite in the lower part of the caldera cliff of the eastern island.

3. — Assongsong Island

Description : This is a typical conide of andesites with a height of 891 m above the sea. The cone is asymmetrical, its northeastern half being steep with an average inclination of 35°, terminating in high precipices on the sea, while the other side of the cone has the profile of a hyperbolic (or catenary) curve, with an inclination of about

25° in the upper part, which gradually diminishes to 10° towards the piano, ending in low lava cliffs on the seashore.

The crater is elliptical, with its longer diameter 150 m in a NE-SW direction, and 100 m across. On the southwestern side of the cone, the flank is largely composed of dark scoriaceous sand, covered with grasses, excepting the piano in which are palm forests here and there. As to the submarine topography of the island, a wide flat that is shallower than 200 m extends towards the southwest, suggesting that this might also be a gigantic submarine volcano of the second cycle which, following the first cycle, terminated in a dissected platform.

Activity : When La Pérouse visited the island in 1786, dark scoriae covered the cone up to a height of 60 m above the sea, and sulphurous smoke veiled the volcano. In 1819 and 1901 it was also active. According to the Japanese Sailing Directory, the volcano mainfested an ash eruption in 1906 which was followed by lava flows discending in several streams on the flank of the cone.

In 1924, two new rock cliffs were seen on the eastern flank of the cone, probably the result of volcanic avalanches, and smoke was issuing from fissures on both of them.

Petrography : Some lava specimens collected from several parts of the shore along the southwestern coast proved to be olivine-bearing two-pyroxene-andesites, except that forming a high cliff on the western coast, which is two-pyroxene-andesite without olivine.

4. — Agrigan Island

Description : This island is elliptical in shape with its longest diameter 8,0 km in a N E direction, and about 6,5 km across, with a height of 965 m above the sea, the highest in the Japanese mandated South Sea Islands. This is also a caldera volcano, consisting of basalts, with a large crater, 2 km long in a NW direction, 1.0 km across and 400 m deep. The crater opens towards the NW, sending lava streams in the same direction.

Palm plantations lie in three places along the coast in (1) the NW part near the place where the lava stream ended, (2) SW part on the lava stream terrace on the coast, and (3) the S-E coastal part.

This might also be a gigantic volcano, nearly 4,000 m high, standing on the East Mariana Ridge, whose upper part alone is visible above the sea.

Activity : As to the recent eruption of this volcano, the account of it by Mr. Someya, the only Japanese who has lived for 30 years in the islands of the Mariana Archipelago, is the most reliable. At the time of the violent eruption of 1917, he was at the Somson (hamlet), situated in a palm plantation on the southwestern coast of the island.

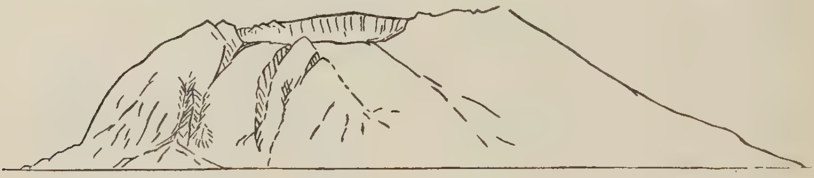


Fig. 3. — **Agrigan Island**

On April 9, about 8-9 a. m. the volcano broke out suddenly without any premonitory symptoms. First, a strong detonation was heard, soon after which a smoke column stood high in the sky accompanied with lightnings flashes. At his hamlet, ash mixed with scoriae, most of them the size of peanuts, rained continuously, so that the people in leaving their houses had to protect their heads with the sacks used for packing copra. The fountain water for drinking became turbid with ash and scoriae. The natives fled into a lava cave near the seashore. Since the eruption continued with full force for almost two days, Mr. Someya also had to flee in a boat to the nearest southern island, Pagan. He saw from the sea, south of the islands, smoke columns with lightning flashes rising from the middle of the caldera where the active crater lies. On his return from Pagan, he found that ash had rained continuously for several days, with the result that some cottages in the middle of the palm plantation on the eastern coast of the island were covered with ash and lapilli about three meters thick. A single lapilli sometimes measured as much as 1 cubic meter.

About one-third of the palm trees in the plantations of this island were damaged by ash that had accumulated, in places, about 0.3 meters thick on the leaves.

Petrography : The lavas at the shore near the anchorage of the Somson are basalts of various kinds, such as olivine-basalt, augite-olivine-basalt with porphyritic structure. The lava between Somson and Mahla, another hamlet in the southwestern coast of the island, is augite-basalt with or without olivine, and augite-olivine-basalt.

5. — Pagan Island

Pagan, which has the outline of a flask, consists of a number of isolated volcanoes. For convenience, we divide it into the North volcano and a volcanic group in the

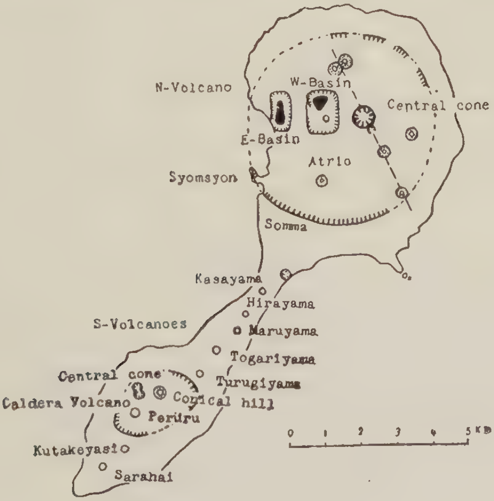


Fig. 4. — Pagan Island

south or Southern group. The former occupies a circular area with a diameter approximately 6.0 km ; the Southern group is shaped like a spindle, with its longer axis about 7.0 km and 3 km across. The neck of the island joining the two parts just mentioned has a width of 700 m.

PAGAN - NORTH - VOLCANO

Description : The north volcano has a double cone of basaltic lavas : the central volcano being 570 m above sea level, rising from the center of the bottom floor of the large flat caldera whose wall has a maximum altitude of 168 m a. s. l.

The caldera is a large basin with a diameter of about 5 km, its wall being covered mostly by lava-flows of the central cone, while in the southern part the wall forms a conspicuous precipice to the flat bottom plain. The Syomsyon (probably same as Somson) rock, a land-tied island, in the western coast is also a part of this caldera wall.

The central cone has a crater with a diameter of approximatly 500 m. On the western side of this cone lie two depression basins of rectangular form, the eastern basin having a longer side of about 1.0 km in a N-S direction, while the E-W is slightly less. The western basin is smaller with a N-S diameter of 800 m and 200 m across. The former, which is deep, is surrounded by steep precipices, about 200 m high at the eastern wall and about 120 m at the western (both above the bottom, which is about 50 m a. s. l.). Near the eastern wall we find two small cones built up of basaltic scoriae. A lake of triangular shape occupies the northwestern corner of the basin. This large caldera basin, probably formed as a depression following on explosion. The western basin, which is not as deep as the former, contains an elongated lake called Laguna, which opens directly to the sea. It is probably the result of a violent explosion.

The central cone stands eastward of the eastern basin, resting on a platform about 250-300 m above sea level, almost flat at the top with steep slopes, the same as is seen on the western side. The upper part of this platform is composed of tuffaceous matter, mixed with large lava blocks, believed to have been formed at the time of the explosion. The present active central cone stands on this platform, with fairly steep sides, being the product of the effusive eruption of fluidal lava in recent times.

The older lava streams that issued prior to 1918, overflowed the crater rim of the central cone, descending to the slopes of the northern as well as of the eastern side, until it finally reached the sea. These lava-flows overflowed the caldera rim in several places.

Many lateral cones stand on the lava field on the flank of the volcano, the highest of them resting on the southeastern flank at an altitude of 292 m. Two lateral cones of approximately the same size lie on the northwestern flank, their heights being 248 m and 224 m above the sea respectively. The above mentioned two cones as well as the lateral cones on the southeastern side lie in a straight line which passes the crater of the central cone, suggesting a fissure.

Activity : As to the activity of this volcano, we have the following data from Mr. SOMEYA. In 1909, the volcano was slightly active, throwing out fire columns often in the night.

In 1917, earth tremblings and fire phenomena occurred from time to time. In May, the same year, Mr. MIZUTANI visited the island to work sulphur directly from the solfatara smoke of the crater pits. A number of miners accompanied him and attemped to lead the smoke into flues for cooling into fluid preparatory to solidification. The smoke, however, was found to be mixed with too much hydrated sulphur for the purpose, so that he abandoned the plan and left the island. At that time, the crater was 40 fathoms deep (probably 50-60 m) and the wall terraced at various heights, probably caused by subsidence of the lava in the crater owing to cooling of the inner part. The deep pit was emitting abundant smoke.

Early in 1923, (1922 according to the Japanese Sailing Directory), tremors were frequently felt and fire columns from the crater appeared every night. The exact time when the activity began is uncertain, but maximum was reached on the night of March 3, when much red scoriae and ash were ejected, covering the neighbourhood of the volcano. Near the cottage on the western piano of the

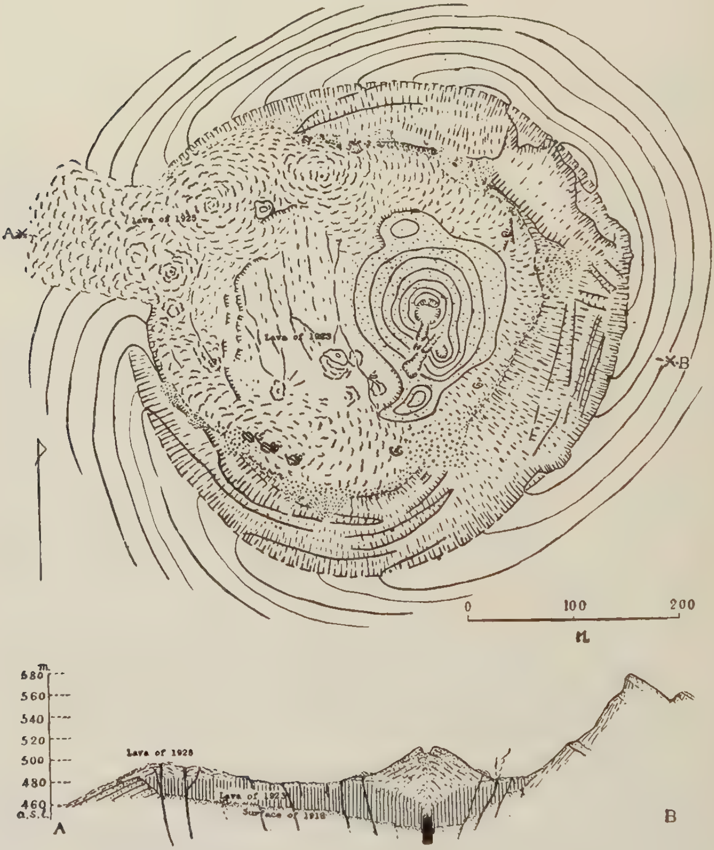


Fig. 5. — Crater of N-Volcano of Pagan Island

volcano at a distance of 2.5 km from the crater, the erupted material accumulated to a thickness of about 1.5 cm.

On March 7, another eruption seemed to have occurred, after which feeble eruptions continued for several weeks, but no more ash rained in the vicinity of the volcano. Ever since this eruption until the beginning of March 1925, smoke has never ceased issuing in thin wisps from the crater.

In the eruption of 1925, (1926 according to Prof. TAYAMA) activities began in February with frequent rains of ash and fire phenomena, while the issue of smoke, accompanied with weak tremors and detonations, markedly increased.

On March 11, at 4 a. m., an extremely fluidal lava of basalt flowed down from the crater on the western flank of the central cone where the wall is lowest, with slopes 28°-30°. The red hot lava stream rapidly flowed to the bottom of the east basin.

In April, it was still active with periodical lava eruptions. Hissing sounds were heard at first, followed by flashes of lightening in the smoke cloud as red hot lava welled up from the lowest part of the crater rim, and overflowed the western flank. The lava flow continued until May 4-5.

In the middle of May, Mr. SOMEYA visited the mountain and saw the lava which was still fuming strongly.

When the writer visited the crater, the bottom was full of new pahoehoe lava, which could be distinguished by its appearance from the older lava that probably issued in 1923, and occupied the central and eastern parts of the bottom floor of the crater, while the new lava of 1925 welled out from the western side, forming several lava hills. The older lava in the central part was depressed 5-10 m deep, many concentric fissures opening up parallel to its margin. On the western side of the crater bottom, many small lava hills like « hornitos » rose at the fissures, sending out sulphur gas still hot. The cone, which is 30 m above the crater floor, has craterlets that show no activity. On the narrow zone between the eastern crater wall and the central cone there are several fissures sending out smoke of very high temperature.

Petrography : The lava of the caldera wall of the Pagan N-Volcano is olivine-basalt of aphyric character. The fundamental platform on which the central cone stands consists of augite-andesites, which extend to the western side where there are two basins. The lava of pahoehoe type that flowed over the flank of the central cone and spread over the vast field of the piano, except the western side, is olivine-bearing-augite-basalt, while the extraordinary fluidal lava of pahoehoe type that issued most recently, in 1923-1925, in the crater of the central cone is an olivine-basalt with porphyritic structure.

PAGAN - SOUTHERN - GROUP

Description : As this volcano was not investigated in detail by the writer, the following brief note is based largely on the observations of Prof. TAYAMA.

The Southern group of volcanoes of this island contains two chainlets of volcanic peaks and a caldera mountain with a central cone. On the northern chainlet, between the narrow isthmus of the island and the caldera , there are several peaks, namely, Kasayama, or Helmet, peak (186 m a. s. l.), Hirayama, or Flat mountain (316 m a. s. l.), Maruyama, or Dome mountain (503 m a. s. l.), Togariyama, or Pointed mountain (541 m a. s. l.), and Turugiyama, or Sword mountain (574 m a. s. l.). These are all made up of various kinds of lava layers, fragmenmental material as well as ash. Kasayama, Hirayama, and Maruyama, for example, are built of olivine-basalts, and their scoriae and ash. The exact manner in which the above mentioned were formed, is, however, not clearly understood. The principal peaks in the southern chainlet of the central caldera are the Kutakeyasi (427 m a. s. l.) and the Sarahai (300 m a. s. l.), both composed of andesites. The lava layers and tuffs of the southern chainlet are irregularly inclined, hence difficult to know the original forms of the volcanoes and the craters from which the lava issued.

The caldera is elliptical in shape with the longer diameter 2.5 km in a NE-SW direction, its wall being clearly visible on the northeastern as well as on the southwestern sides, where the steep slopes are over 200 m high. The central cone has a twin crater, and the northern rim of the north crater culminates at a height of 548 m a. s. l. Although the eastern half of the cone rests on the caldera floor, the western flank touches the sea, one of its radial valleys being deeply dissected and distinctly visible from quite a distance. The volcano is active, constantly sending out fumes from several parts of the crater. On the southwestern foot of the central cone there is a small lateral hill called Perüru, consisting of scoriae, lava detritus, lapilli, and porous lava of andesites, with fumes sometimes issuing from the top, southwestward over the caldera wall, having flowed down the steep slope into the sea.

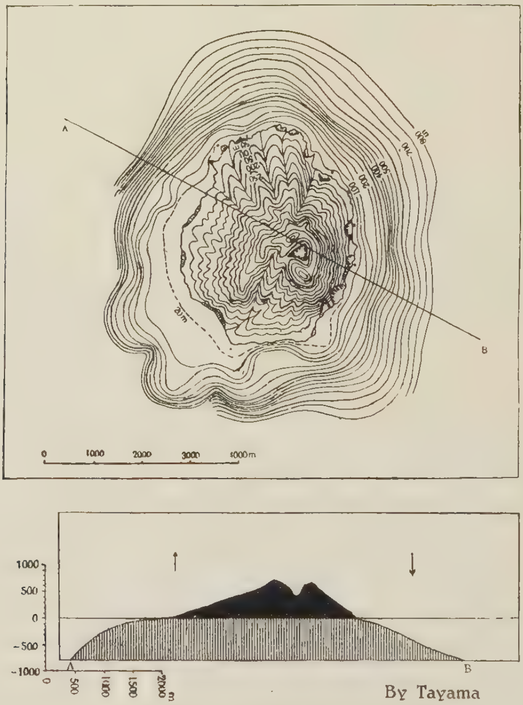
On the northern foot of the central cone, there is another cone with a crater, 368 m a. s. l., or from 60 to 70 m from the bottom floor of the caldera. This cone poured out large quantities of lava, which filled the caldera bottom and flowed down to the sea from both sides, east and west.

In some places at the western foot of the central cone, hot springs are found near the shore.

According to Mr. Someya, the central cone of the caldera in the southern group was very active during the years between 1929 and 1930, sending out large quantities of smoke from the solfatara in the crater.

6. — Alamagan Island

Description : This volcano is a conide with a small crater on the top, lying slightly east of the center. The eastern side is therefore very steep with an inclination, in places, of 45°, while the general slope of the other side is only 20°. The wave-cut cliff is high on the eastern coast and low on the opposite side. This volcano is greatly dissected by radial valleys, especially on the northern side, where there is a deep valley with several ravines at the head. The lava specimen from the shore of the anchorage is an olivine-basalt with augites.



By Tayama

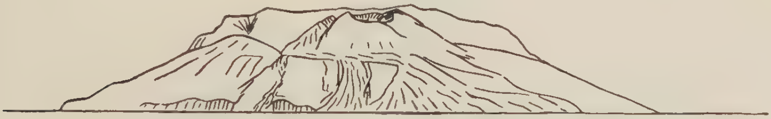
Fig. 6. — **Alamagan Island**

The palm plantation is in the southern part, where there is a settlement near the opening of the valley.

Judging from the submarine topography, this volcano is probably built up also on a platform, most likely of volcanic origin. According to Mr. Someya, there is a solfatara, emitting smoke on the northwestern flank of the volcano.

7. — Guguan Island

Description : This island, with a longer diameter of 2,8 km in the N-S direction, and 2.0 km across, is 310 m a. s. l. The eastern half of the cone is occupied by an older volcanic mass that is markedly dissected. The northwestern side of the volcano, where a triple volcano stands, has been the scene of eruptions in recent years. The Somma of the triple volcano is seen clearly on the northern side, being partly covered with a new lava stream. (The older volcanic mass on the eastern side may be a continuation of the Somma).



View To S-E

Fig. 7. — **Guguan Island**

The central volcano is 248 m a. s. l. A cinder cone with double craters had formed not very far up at different times in recent years. The outer crater of the two opens toward the west, whereas the other is a perfect cone. The double craters are coated with white substances, probably sulphur, sodium sulphate, etc. which can be seen from a distance.

The lava, which is of a-a type and is a basic andesite, issued from the central cone and spread over the western slope with an angle of 15°, exactly in the shape of a fan and poured into the sea. The new cinder cone as well as the lava streams, present such a fresh appearance that they probably erupted in recent years, although no one knows the exact date. According to seafarers, who often touch at this island, there is a hot spring on the shore in the western coast where new lava had flowed into the sea.

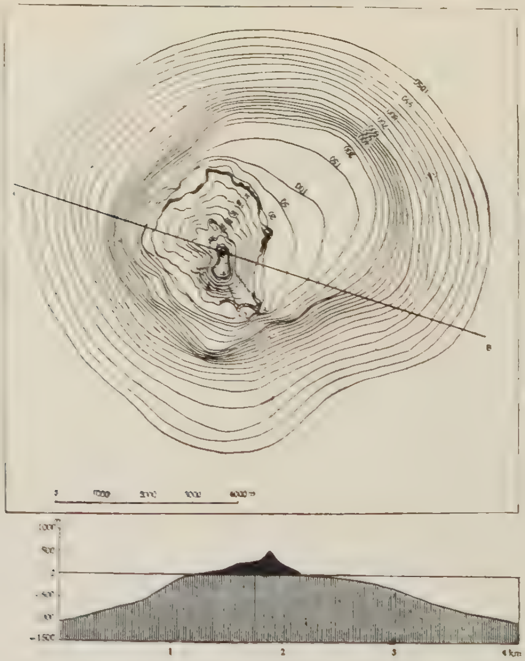
Activity : It is said that in 1819, the northernmost of the three craters (probably the triple volcano), which lies on the western side of the island, was very active.

In 1901 there was an active volcano in the northern side (western ?) of the island, covered at that time with ash. According to the Japanese Sailing Directory there is a solfataric pit on the northern side of the central crater.

Petrography : The lava specimen which Prof. TAYAMA collected in 1938 from the highest part of this island is two-pyroxene-andesite, while the new lava of a-a type that came from the central cone is olivine-augite-andesite of extraordinary basic character.

8. — Sarigan Island

Description : This island is of triangular shape, with their bases each from 2.5 to 3.0 km long, and 549 m a. s. l. The southern side of the volcano is slightly steeper than



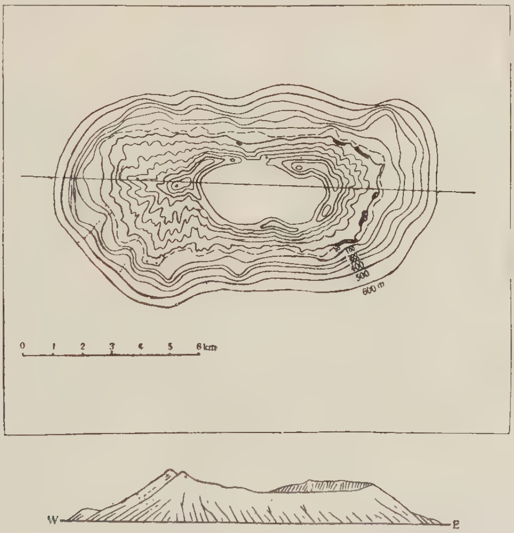
By Tayama

Fig. 8. — Sarigan Island

the others, and the lava bluff that borders the whole island is also high on the same side. The volcano has two peaks of almost the same height, the southern peak resembling a conide although no distinct crater is discernible. A rock specimen from the shore of the anchorage is an olivine-bearing two-pyroxene-andesite. As to the submarine topography of the island, a shallow flat stretches NE ward giving the impression that a vast lava field formerly occupied this part, which later was eroded by the waves. The present island volcano then rose on this platform as the result of a secondary cycle.

9. — Anatahan Island

Description : This is a long island with a length of 9 km EW and 4 km NS, and 788 m a. s. l. The volcano has a large elliptical caldera, 4 km long from E to W and 2 km across, whose bottom floor, in the rainy season, seems to be a marsh. Whether this is a single volcano with a caldera or a twin volcano with twin caldera is a question awaiting solution pending further geological research.



By Tayama

Fig. 9. — **Anatahan Island**

At any rate, the form of the caldera is characteristic, with an extraordinarily elongated shape.

Erosions abound on this volcano and numerous ravines dissect the cone, probably because the surface of the volcano is covered with thick tuffaceous material, especially on the S W side of the mountain. A palm plantation lies on the southwestern coast of the island. There is a hot spring ashore near the southern coast where are scattered the fishermen's cottages.

Petrography : There are many layers of lava, intercalated with glassy rocks and pumice along the southwestern part, all of which are augite-andesites with sometimes phenocrystals of olivine.

Chemical Analyses of the Rocks.

	I.	II.	III.	IV.
SiO_2	53,94	52,80	51,46	50,30
TiO_2	—	0,86	—	1,06
Al_2O_3	19,59	21,39	17,66	18,12
Fe_2O_3.	2,69	2,10	2,62	4,50
FeO	6,65	6,22	8,18	6,66
MnO	0,17	0,14	0,20	2,21
MgO	2,44	2,40	4,57	4,80
CaO	9,80	10,50	11,00	10,80
Na_2O	2,67	2,76	2,40	2,50
K_2O	0,67	0,62	0,63	0,70
P_2O_5	0,12	0,15	0,12	0,16
H_2O (+) . . .	0,15	0,10	0,32	0,23
H_2O (—) . . .	0,10	0,06	0,07	0,13
S	—	0,01	—	0,02
TOTAL	99,78	100,13	100,13	100,19

I. — Hypersthene-augite-andesite from the south-eastern foot of the Uracas volcano; new lava of a-a type, analysed by S. TANAKA, Earthquake Research Institute, Tôkyô Imp. University.

II. — Two-pyroxene-andesite from the southern coast of the Uracas volcano; new lava of a-a type (slightly older than I). Analysed by Imp. Jap. Geological Survey.

III. — Augite-olivine-basalt from the central crater of the Pagan North-volcano; new lava in *corda* of pahoehoe type (1925). Analysed by S. Tanaka, Earthquake Research Institute.

IV. — Augite-olivine-basalt from the central crater of the Pagan North-volcano; new lava in *corda* of pahoehoe type (1925). Analysed by Imp. Jap. Geological Survey.

Concluding remarks

From what has been said, the following facts are known of the Uracas volcanic chain of the Mariana Islands.

(1) The volcanoes lie on a finely arcuate zone, and generally at intervals of about 50 km, although it varies between 10 km and 175 km.

(2) Every island of the chain is nothing but the upper part of a gigantic submarine volcano, rising from depths of from 2,000 to 1,500 m under the sea. So far as it appears above the sea surface, the volcanic forms are classified as follows:

I. Volcano with a caldera or Homate; (a) with no central cone, as seen in Anatahan and Agrigan. (b) with a central volcano, as in the case of Uracas, both the North-volcano and the Caldera volcano in the Southern group of the Pagan island, and the Guguan. The Maug volcano has submarine domes in the central part of the caldera.

II. Conide; examples are the cones of Uracas (the central cone of the destroyed caldera), Assongsong, Alamagan, and probably Sarigan, although the crater of this last has not been seen so far.

III. Basin or Maar; both basins of the Pagan North volcano belong in this class.

(3) Types of eruption.

I. An explosive eruption emitting abundant juvenile ejectas and ash, as in the case of the caldera of Agrigan. The Assongsong showed also the same type of eruption, sending out fine scoriaceous sand of dark color.

II. Fluidal lava eruptions: *a)* a type of activity similar to that in the crater of Vesuvius in recent years; the formation first of a small cinder cone as the result of

Strombolian activities, followed by emissions of liquid lava of pahoehoe type.

The central cone of Pagan-North-volcano is of this type, the eruptive manifestation of this crater being similar to those in the years 1912-1923 of the Miharayama crater, in Oosima, belonging to the Sitito volcanic Islands, although in the case of Pagan, the lava is more fluid.

The lava eruption of the Caldera volcano in the Southern group of Pagan island seems to have been of the same type, although its date is unknown.

b) Another type is the Strombolian form of eruption, in which liquid lava of a-a type flows over the crater rim or from the flank of the volcano. The Uracas volcano belongs to this type.

c) A type combining the above mentioned two is seen in the Guguan eruption, in which a double cone, exceedingly high compared with the Somma, is formed after which lava of a-a type issued from the crater as well as from the base of the cone.

The Uracas chain does not seem have had any large explosions of the Bandaisan type in recent years, although the Sitito Islands frequently showed such ultravolcanic outbreaks; an example being that of Torisima in 1902, when the entire population of the island was killed by falling debris. This is probably connected with the fact that the caracter of the activity of the Uracas chain is mostly effusive at present.

(4) Regarding the Southern group of Pagan island as an independent volcano, ten volcanoes in nine islands have been described. If the Guguan and the Caldera volcano of the Southern group of Pagan are included as active volcanoes, although the dates of their eruptions are unknown, there are then six active volcanoes among the ten of the Uracas chain, while Alamagan seems to have a solfatara, and Anatahan contains a hot spring, a last trace of the volcanic energy. As a whole, therefore, volcanoes of the Uracas chain are more active than those of the Islands of Sitito and Iôzima in Japan proper.

(5) So far as we have examined, the rocks of the volcanoes of the Uracas chain belong to the basalts and basic andesites, whereas in the chains of Sitito and Iôzima, andesites ; with basalts next in order of abundance abound, while local occurrences of acidic rocks of trachytic and lipartic character are also known [1]), notwithstanding that not even a solitary piece of these two rocks can be found in the former. Naka-iô-Zima, in the Iôzima Islands, one of the nearest active volcanoes from the Uracas island, consists of acidic andesites and trachyandesites with silica contents ranging from 58,91 % to 60,82 % according to Dr. H. Tsuya, which greatly exceeds those of the Uracas chains. Notwithstanding such a local difference between the rocks of the Uracas chain and other chains lying north, all these are closely related from the petrographic point of view, showing the Pacific type of rocks.

(6) We have thus shown the relations between the chains belonging to the Huzi zone and the Uracas chain of the Mariana Islands from the geographical point of view, the intimate relation being confirmed also by both volcanological and petrographical studies.

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[1]) Tsuya H. — *On the Volcanism of the Huzi Volcanic Zone, with Special Reference to the Geology and Petrology of Idu and the Southern Islands.* Bull. Earthq. Research Institute, XV (1937, Part I).

List of the Volcanoes in the Uraca

Volcano Islands	Dist. from volcano of preceeding No. (km)	Geographical position		Diameter of Island (km)				Height (m) a. s. l.
		N	E	Length		Breadth		
1. Uracas	—	20°38′	144°53,5′	NS	1,6	EW	1,5	319
2. Supply Reef	55	20°8′	145°6,0′	—		—		8,2
Maug	10	20°1,5′	145°13,7′	—		—		—
N-Isd.	—	—	—	EW	1,5	NS	0,5	228
W-Isd.	—	—	—	NS	2,3	EW	0,8 - 0,1	180
E-Isd.	—	—	—	NS	1,9	EW	0,9	218
3. Assongsong	43	19°40′	145°24,3′	NNE	3,4	NNW	2,6	891
4. Agrigan	98	18°45′	145°40,2′	NS	9,7	EW	6,2	965
5. Pagan	65	18°6,7′	145°47,6′	NE	16,3	NW	0,7	—
N - Volcano	—	—	—	NNE	7,0	EW	5,0	570
S - Group	—	—	—	SNE	8,5	EW	0,7	574
6. Alamagan	50	17°36,2′	145°50,2′	NS	4,5	EW	3,3	744
7. Guguan	30	17°18,9′	145°50,9′	NS	2,7	EW	2,0	310
Sealandia bank	45	16°33′	145°51,0′	—			0	0
8. Sarigan	22	16°43′	145°47,0′	NS	3,0	EW	2,4	549
9. Anatahan	37	16°21,4′	145°40,2′	SW	9,0	NS	3,5	786
Esmeralda bank	175	15°0	145°16,0′	—		—		—

Olv = Olivine, Aug – Augite, Pyrx = Pyroxene, 2 = two, And. = Andesite,

Chain of the Mariana Islands.

Circumference (km)	Area (km)	Form of volcano	Rocks	Recent activity	Hot springs and Solfatara
5,5	2,16	Con. in a cald.	Olv-2 Pyrx-And.	Constantly active, Strombolian type	Solf.
—	—	—	—	—	—
—	2,29	—	—	—	—
—	0,43	Cald. with domes as centralvols.	Olv-Bas. Aug.-Olv-Bas. Aug.-And. 2 Pyrx-And.	—	
—	0,76			—	—
—	1,10			—	—
10,0	7,53	Con.	Olv-2 Pyrx-And. 2 Pyrx-And.	1906 Ash explosion	Solf.
26,0	44,11	Cald.	Aug.-Bas. Aug.-Olv-Bas.	1922 Expl. eruption	Solf.
42,0	45,90	Double cone in large cald.	Olv-Bas., Olv-Aug-Bas. Aug-And.	1923, 1925 Strombolian eruption	Solf.
—	—				
—	—	Vol.- peaks and cald-vol.	2 Pyrx-And., Aug-And., Olv-Bas.	—	Solf. Hotspr.
13,0	12,62	Con. with small-cr.	Aug-Olv-Bas.	—	Solf. ?
7,5	3,90	Triple vol.	2-Pyrx-And. Olv-Aug-And.	Eruptions in recent years	Solf. Hotspr.
—	—	—	—	—	—
10,0	4,75	Con. without recog. cr.	Olv-2 Pyrx-And.	—	—
25,0	32,99	Vol. with elliptical cald.	2 Pyrx-And., Olv-And.	—	Hotspr.
—	—	—	—	—	—

Bas. = Basalt, Vol. = Volcano, Con. = Conide, Cald. = Caldera, Cr. = Crater

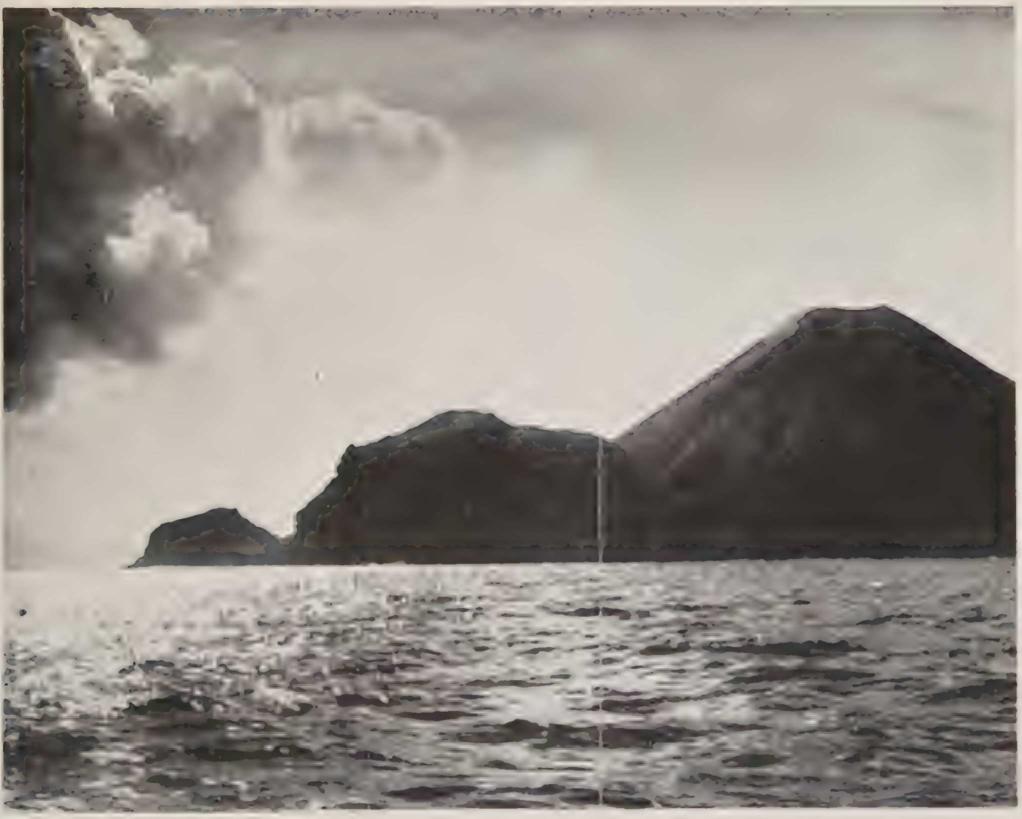
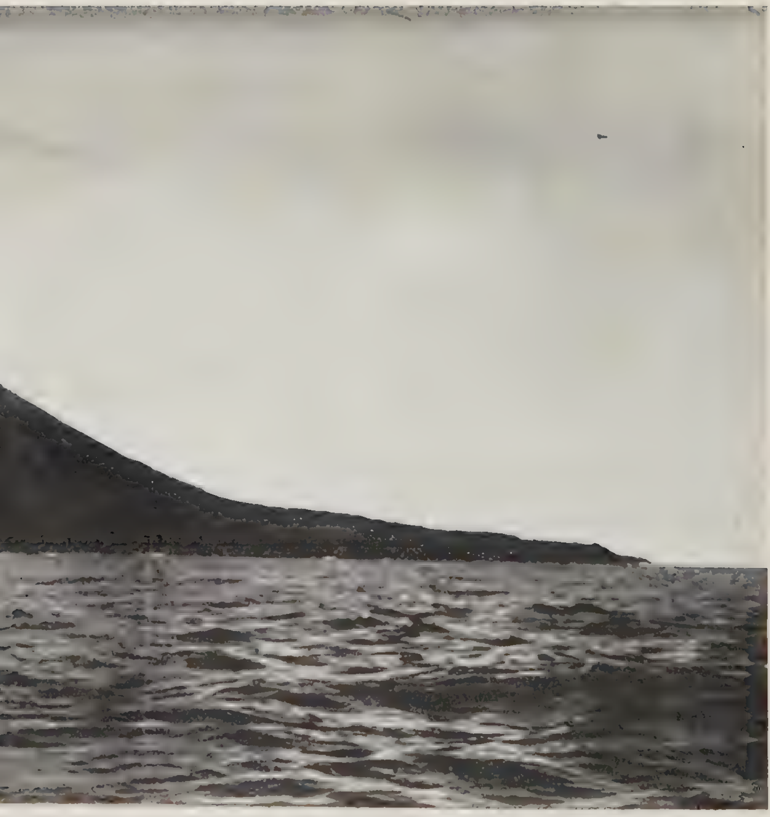


Fig. 10. — **Uracas Island :** — The typical conide of Uracas (319m a. s. l.). View of the south spread over the piano forming a vast lava field as is seen in the foreground. Both of the two hil is high as 144m a. s. l.

PLATE I.



astern side ; the a-a lava flowed out from the lower part of the flank and
s at the light are the relics of the Somma wall and that standing in front

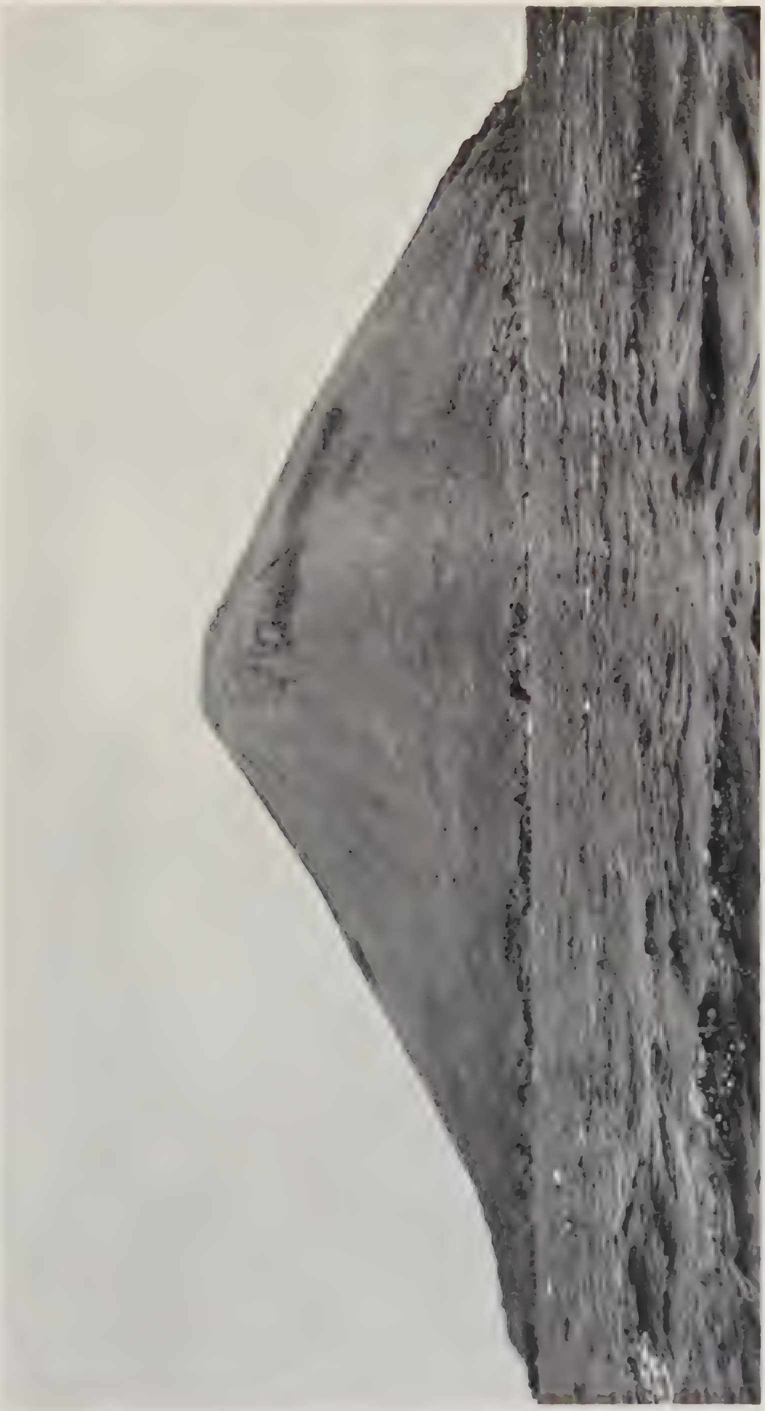


Fig. 11. — **Assongsong Island.** View of the western side from the sea shore near the western coast.

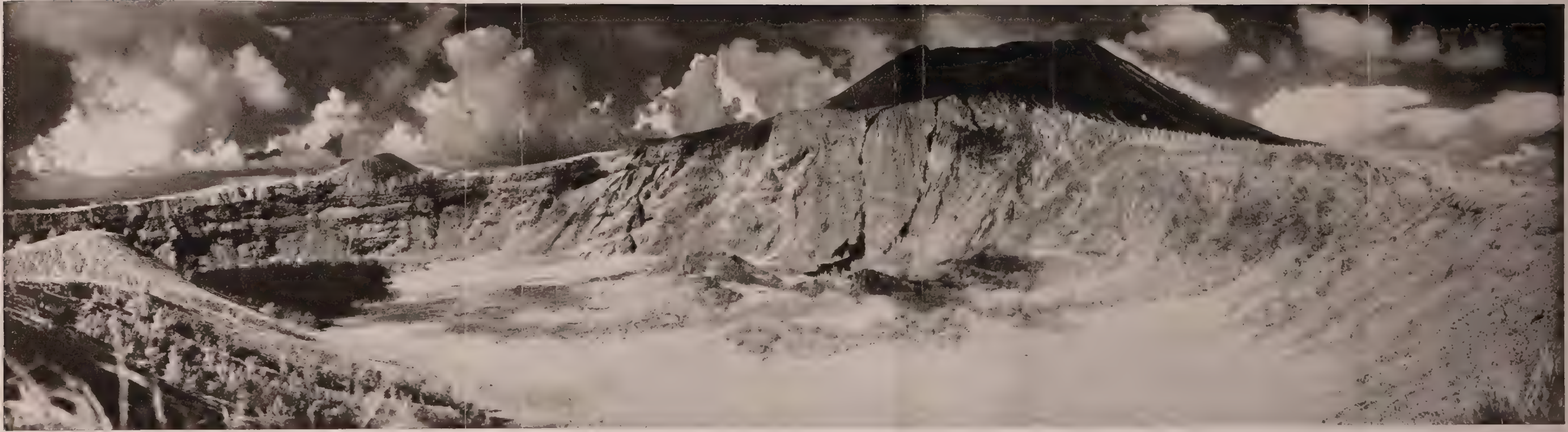
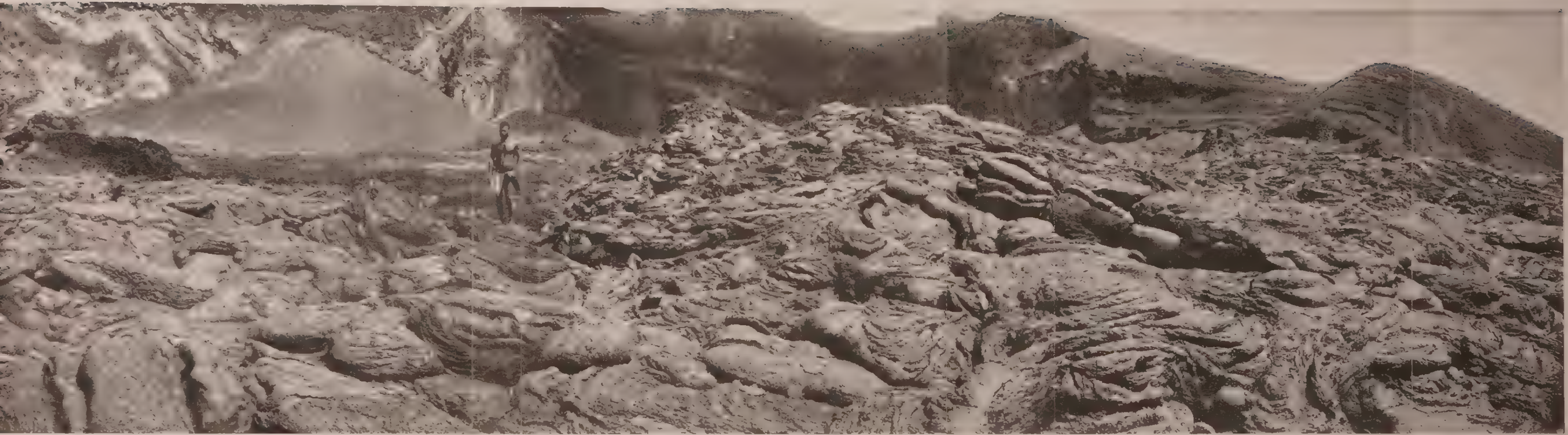


Fig. 13. — **Pagan-N-Volcano, Eastern Basin.** The view from the top of the western wall of the Eastern Basin with the central cone in the background; in the foreground, the hanging precipices with thin veins of liquid lava descending down to the bottom floor where lie two small cones of basalt. At the left: a parastic cone of homate shape standing on the lava field in the rear, and in the foreground a triangular lake in the Eastern Basin.

PLATE V.



. 14. - **Pagan-N-Volcano.** A view of the lava mound standing at the western part of the crater bottom near the wall. At the right, typical pahoehoe lava; at the left a cinder cone, 30 m high above it's foot, where a lava cliff, about 5-10 m. high is recognized as the fault scarp formed by the depression of lava field after the 1923 eruption.

PLATE VI

IDEZÔ TANAKADATE — *Volcanoes in the Mariana Islands in the Japanese Mandated South Seas*

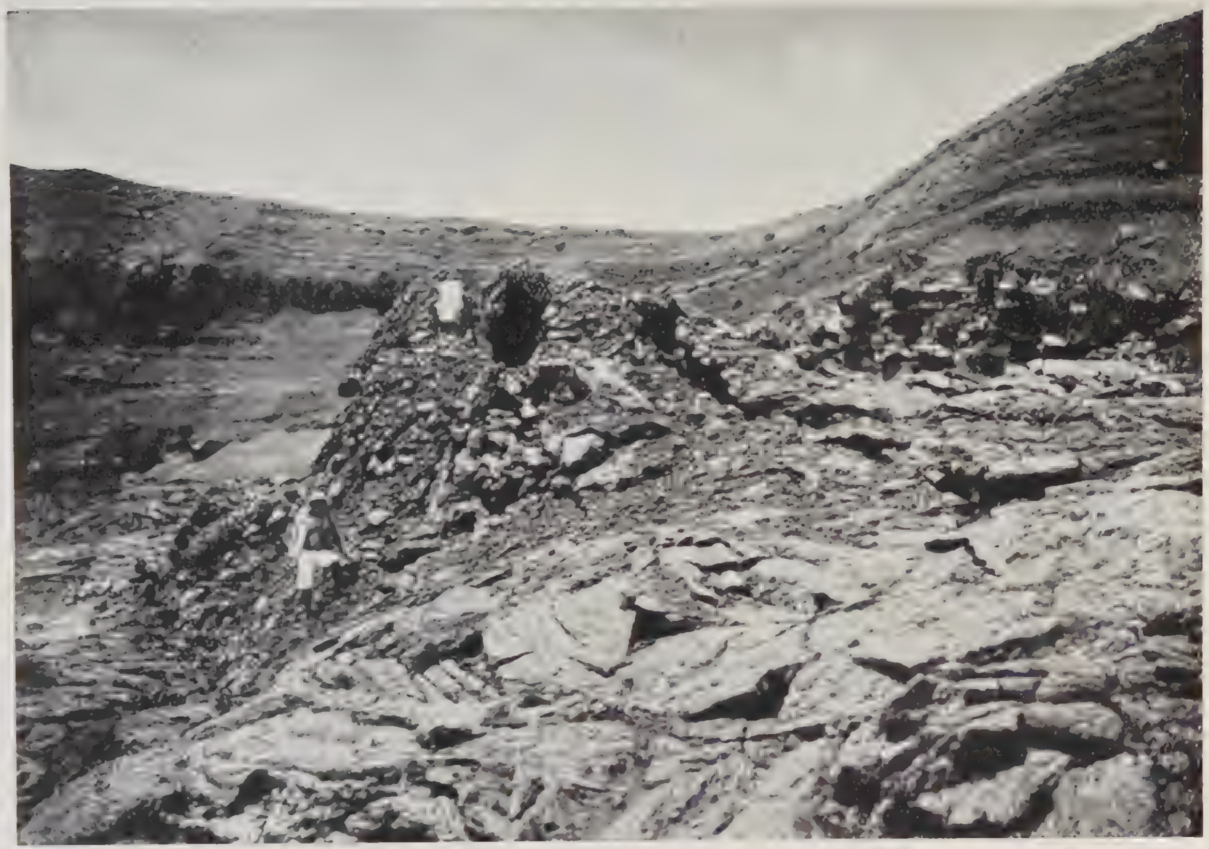
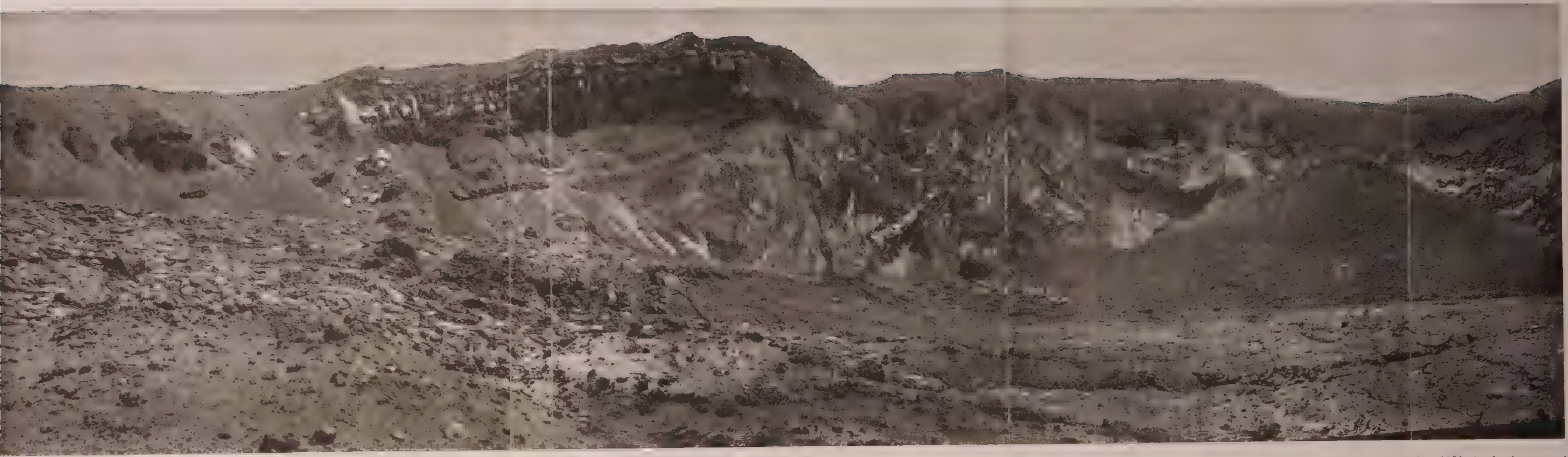


Fig 15. — **Pagan-N-Volcano.** A scoriaceous lava hill crowned with a deep crater hole, about 7 m high from it's foot, standing on the fissures running in a concentric direction parallel to the crater wall on the bottom floor.



g 16. — **Pagan-N-Volcano.** Panorama view of the crater of the Pagan-North-Volcano. The standpoint is situated on an elevated portion of lava, a little apart to the west from the center of the crater bottom floor. At the right: The lava field, formed in 1923, in the foreground, the cinder cone, about 30 m high above it's foot, in the rear. At the left: the mounds of pahoehoe-lava, formed in 1925 on the bottom floor at the western part of the crater *(I)*.

PLATE VII.

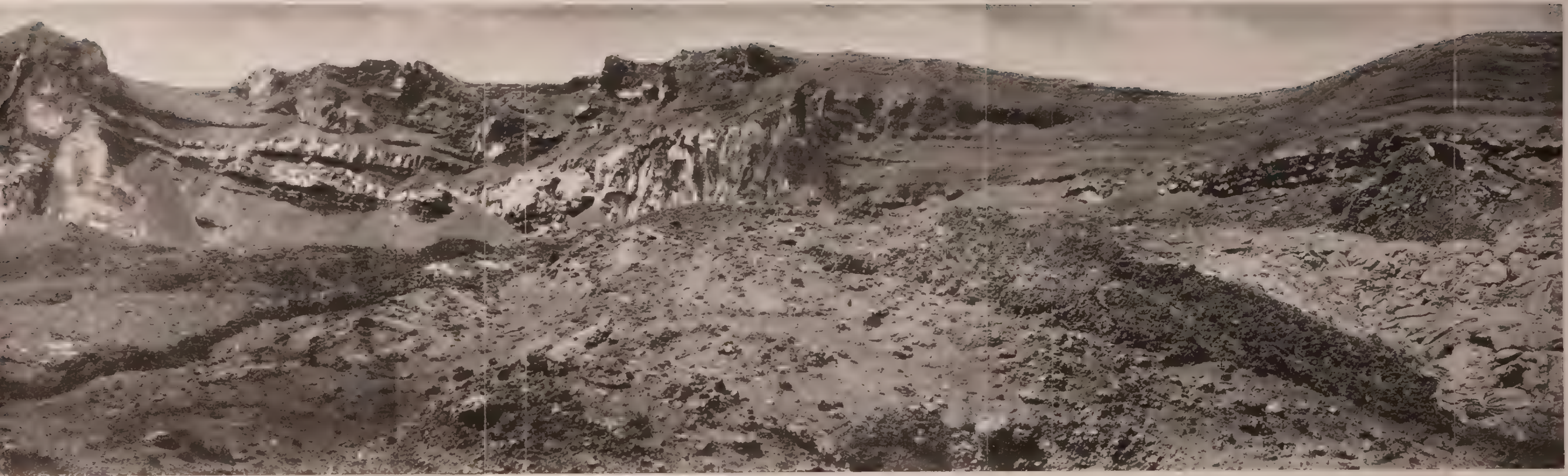


Fig. 16. (II)

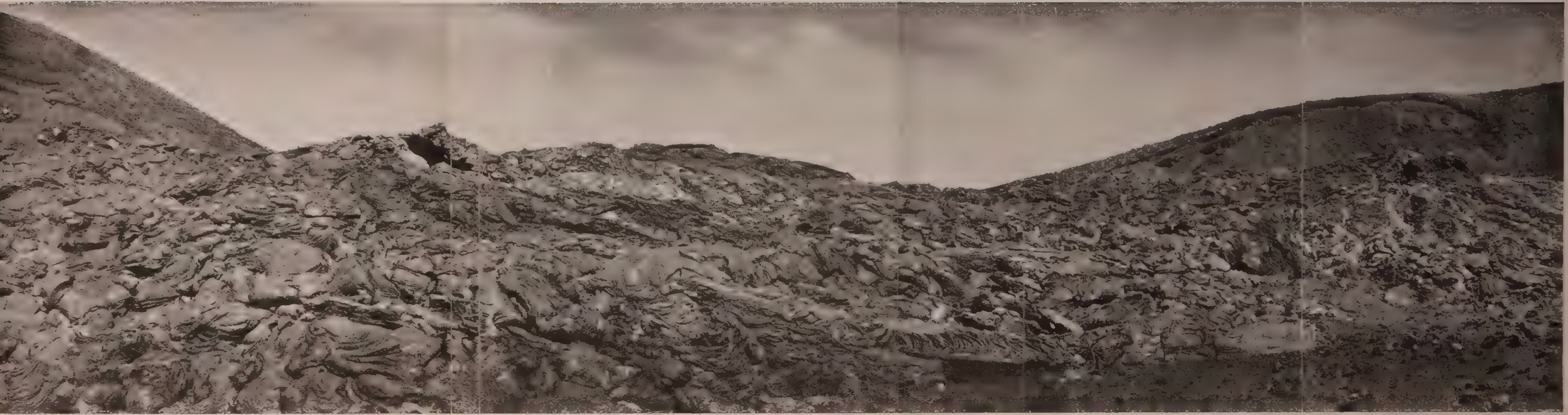


Fig 16. · *(III)*.

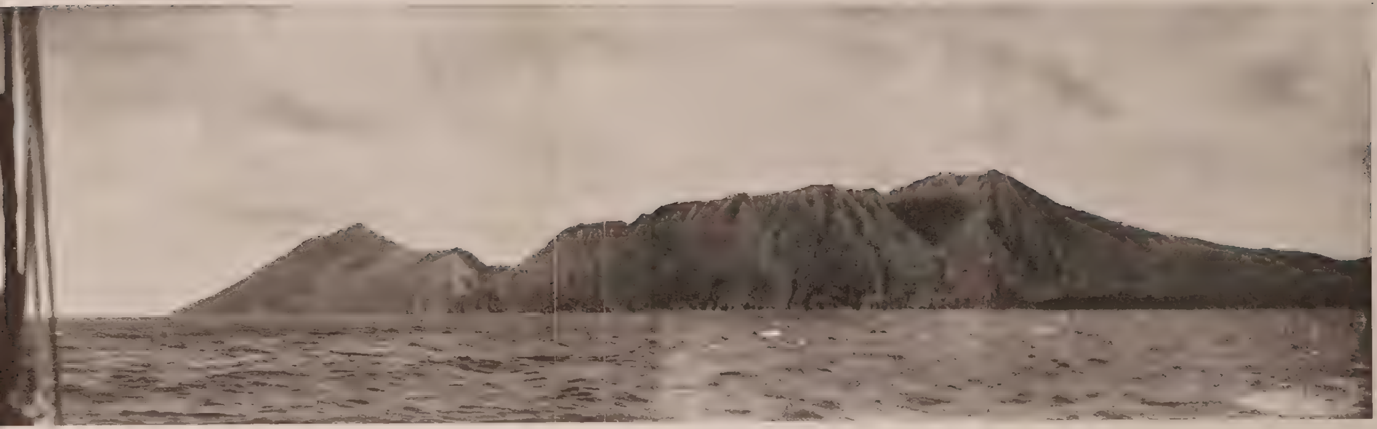


Fig. 17. — **Anatahan Island.** The general view of the northwestern side of the volcano from the sea.

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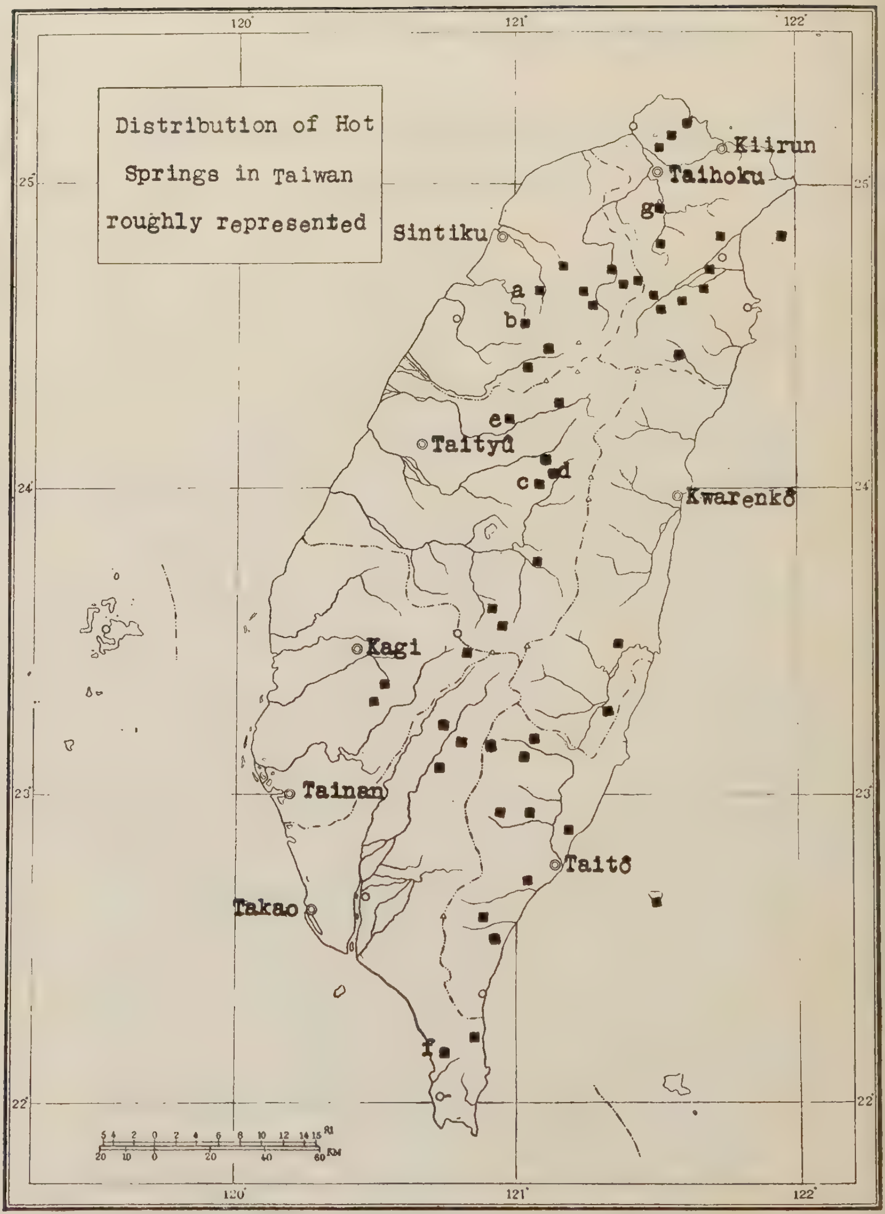
On some thermal springs of Taiwan, Japan

(With 1 text-figure)

I. In the island of Taiwan (Formosa) there are numerous thermal springs. Many of them are found in and around the extinct volcanic group of Daiton immediately north of the city of Taihoku, and consequently there are many popular holiday resorts of which Sōzan, Hokuto and Kinzan are representative. A few hot springs of this category are also found in small volcanic islets of the eastern coast of the main island. Almost all of them are fumarolic and solfataric remnants of past volcanic activities. According to the general tendency in the geological classification of thermal springs these may be called « volcanic », while there are many more « non-volcanic » thermals widely distributed outside these volcanic tracts. The latter group comprizes numerous hot springs that are distributed in the area of the axial mountain range consisting chiefly of thick slates with occasional accompaniment of sandstones and calcareous bands. The rock formation of the axial range is as a whole very intensely folded, crumpled, faulted and thrusted, naturally producing fissures and joints of various magnitudes in the slate formation.

The backbone range of Taiwan, being the result of a geologically very recent crustal deformation, is as a whole very high and steep: it is about 3,500 m or thereabout in average height and culminates in peaks a few hundred meters higher. Physiographically it is in the infantile stage of evolution, and is dissected into a number of blocks or masses, large and small, by steep and deep river gorges. The hot springs of this second group which are the chief object I am interested in at the present moment are situated at the foot of these mountain blocks,



II. It is very difficult at present to give the total number of these thermal springs because there are many of them in inconvenient savage sections of the country. Of about 50 of them we have information, however,[1] geologically they are unknown, although the waters of some of these springs have been chemically analyzed by the Central Research Institute of the Government of Formosa.[2]

Ooe, in his paper quoted,[1] plotted both « volcanic » and « non-volcanic » hot springs of Taiwan on a small map and connected them with lines that are said to coincide with dislocations known up to that time. Many of his thermal fault lines run NE-SW in general while many others run crosswise. Hot springs, according to him, flow up through these faults, especially at the junctions of different dislocations. This is a very popular way of thinking, and is of course quite reliable occasionally. Especially is this true with hot springs in certain limited spaces, as for instance, in a volcanic field. On the other hand, however, one may unconsciously blunder, by reasoning in a circle that hot springs come out along dislocations, and that because there are hot springs, there must be dislocations.

The tectonic theory, so to say, of thermal springs inevitably expects dislocations of certain magnitude and depth, ascribing the source of heat to the geothermal gradient in a wider sense. In this case dislocations are considered indispensable as passages of waters. Water, however, can pass through more minute and irregular fissures and cracks equally well wherever such exist. Depth, no doubt, is responsible for heat, though the gradient may differ from place to place. In the case of the mountain hot springs of Taiwan the significance of the geothermal gradient is quite evident because the down-sinking surface water flows out heated at the foot of the mountain blocks instead of the hot water coming up from an unknown abyss as in most other cases. Some examples are given below.

a) The Inouye Hot Springs, Sintiku Prefecture. They are situated at the western foot of a mountain mass

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[1] Ooe J.: Journal of Geography, XL. (1928).

[2] Rep. Techn. Dept. Central Res. Inst., Governm. Formosa, 6. (1930).

(Mentoyusan, 1,796 m), at the height of about 450 m above sea level: warm water flows down from the ceiling of a small cave in the wall of the cliff of the valley, about 15 m above the bottom. The rock formation is very strongly folded and thrusted in this neighbourhood. The spring water is simple and is about 40° C.

b) The Kaminosima Hot Springs, Sintiku Prefecture. These alkaline springs, having a temperature of 42°-43° C. flow down from a steep cliff at the northern foot of a mountain block about 600 m above sea level. The highest of the hot springs, arranged more or less along fractures, is nearly 30 m above the bottom of the valley. This region is surrounded by mountains of far greater altitudes.

c) The Sakura Hot Springs, and

d) The Mahebo Hot Springs, Taityū Prefecture.

These are within the valley surrounding the western foot of the mountain mass of Nōkō-zan. The former are situated at the northwestern foot of the Kita-Bandai-zan mountain mass (2,200 m), and are about 900 m above sea level, the springs on the valley wall being about 5-6 m above the valley bottom. The temperature is about 60° C. The latter, about 1,000 m above sea level, are found on the cliff at the western foot of the mountain mass of Antaku-zan which is 2,346 m at the top. The hot water, more than 80° C. in temperature, flows down from the fissures in the naked valley wall into the bottom about 10-15 m below. Here the quantity of the thermal water is enormous. The spring waters at these two places are both alkaline and very clear.

e) The Meizi Hot Springs, Taityū Prefecture. Here also a clear, simple hot water flows out of the fissures formed in the slate wall at the foot of a high mountain block, about 2,300 m. The quantity is considerable, and the temperature is about 45° C, though it is quite variable.

f) The Sizyūkei Hot Springs, Takao Prefecture. A small N-S ridge, about 1,000 m at the top, of slate and sandstone is covered at its southern margin by deposits of river terraces : warm water flows out at a few places where the terrace deposits are locally eroded away. Here the hot springs are situated about 50 m above sea level, being very near to the shore.

g) The Urai Hot Springs, Taihoku Prefecture. Urai is about 25 km south of Taihoku, situated along the eastern foot of an unnamed mountain mass, about 1,000 high. Here, on the slope of the valley, at an altitude of about 170 m, and about 30 m above the valley bottom, a few hot springs of an alkaline nature are found, with a maximum temperature of about 80°C. Y. ICHIKAWA once conjectured the hidden existence of diabase dykes, of which or of any igneous rocks, we find no trace in this region [1]). Here again, the argument runs in a circle, hot springs being, in the author's mind, products of volcanism and volcanic rocks being expected because there are hot springs.

There are a few more hot springs that I have personally visited and about which I have made some observations. But almost all the essential features observable in all these hot springs are quite similar, the difference being the quantity and the temperature of the spring waters. It is noteworthy that, as far as I am informed, of the quantity of water and the temperature in these hot springs are quite variabile according to the season. During rainy periods the springs tend to a lower temperature and increase in quantity, while in dry and hot months the springs are warmer.

The features common to all these hot springs may be summarized in the following way.

1) All these hot springs are almost exclusively simple or alkaline in nature, with occasional traces of sulphur which might be considered as having been derived from pyrites often found in the black slate formation.

2) Springs flow out of the fissures of valley walls more or less above the bottom of the valleys.

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[1]) Explanatory Text to the Geological Sheet « Sinten ». (1934).

3) Hot springs are situated along the foot of more or less isolated mountain blocks that vary in height from several hundred to about 2,000 m. These mountain masses are densely covered by thick vegetation, and there is abundant ground water everywhere in the regions under consideration, as is evidenced by waterfalls of various magnitudes.

4) The rock formation constituting the mountain region including the hot spring sites is, as stated elsewhere, very severely crumpled and shattered, producing fractures, joints, dislocations, thrusts, etc. It is very easy for the ground water, therefore, to sink down through the rock formation by these fissures, with the result that the water becomes heated by the geothermal gradient during its passage downward. The variability of the temperature and the quantity of springs referred to above conform to this generalization.

In a word, these hot springs belong to the « *Absteigende Thermen* » of E. KAYSER [1]) which seems to be quite common in the non-volcanic, tectonic regions of Europe [2]). These by no means should be uncommon in other parts of the world, although « *Aufsteigende Thermen* » seem to be considered as more common.

III. Here I should like to turn to the problem of the geothermal gradient of Taiwan. Although there are a number of deep oil wells, the deepest hitherto driven being

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[1]) *Lehrbuch der Geologie*, I Bd. (1923), p. 434. An ideal profile through the thermal region of Baden near Zürich is given as an illustration of the « *Absteigende Thermen.* » (p. 432).

[2]) J. WALTHER, in his popular and elementary « *Vorschule der Geologie* » (1920), mentions (p. 110), as one of the chief origins of thermal springs, this downsinking of water through fissures of rocks, illustrating with a schematized profile of such occurrences. He shows how the snow on the top of a mountain mass passes through the rock mass and flows out at the foot as hot springs. Perhaps the « new idea » on the genesis of the thermal waters of Aix-les-Bains presented by L. MORET and G. SCHNEIDER may be regarded as a new datum for the validity of the downsinking theory of hot springs (Bull. d. l. Soc. Scient. du Dauphiné, p. 1-16, 1934).

3,000 m, the geothermal measurements have not been carried out scientifically 1). We have, therefore, no available data concerning the geothermal gradient of Taiwan. If, however, it happens that its value is « abnormally » small by whatever cause, the heating of the downsinking water may be also abnormally rapid for the distance of passage. The apparently « abnormal » value of the geothermal gradient of Taiwan, which will be deduced from some of the hot springs that are considered to be downsinking in origin, and the vertical distance of the passage of the water, may be explained by this way of thinking. It seems there are several causes that shorten the range of the geothermal gradient.

First, the island of Taiwan is an arcuate folding mountain of the Alpine pattern formed in a geologically modern age 2). It is, therefore, possible that the heat produced by the crustal deformation still remains within the disturbed zone. **Bröger**, in one of his papers pointed out that the rock temperature can be higher in the neighbourhood of « Deckengebirge » if the rock is a bad conductor of heat 3). And that slate is a bad conductor is generally accepted.

Strictly speaking, we have much to discuss as to what is the « normal » value of the geothermal gradient. As is well knowm, the more recent values obtained in Simplon, St. Gottard and other places are far smaller than 33 m. In North America where deep oil wells provided the chances of measuring underground temperatures more systematically, it is recorded that the geothermal gradient of Californian oil fields is much smaller than the « normal » 4). The un-

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1) M. **Ishizaki** mentions a couple of records taken in a few oil wells: they need not be taken into consideration here, because they do not represent the general tendency. Jour. Jap. Assoc. Petrol. Technologists, 6 (1938), N.º 2.

2) I. **Hayasaka** — *The Formosa Earthquake of April 21, 1935, Geologically considered:* Jubilee Publication in Commem. Prof. **Yabe** (1939).

3) Glückauf, 1931, pp. 545-551.

4) **Darton**: U. S. Geol. Surv. Bull. 701 (1920).

derground temperature increase is quite conspicuous in the oil fields of Japan proper, too [1]. KÖNIGSBERGER and MÜHLBERG once reported that the geothermal gradients in Mexico and Borneo are almost all much smaller tham the « normal »[2].

Secondly, the very strong solar radiation in the tropical and sub-tropical low latitudes heating the bare surfaces of very deep rock cliffs, constantly for ages may have raised the temperature of the superficial layers of the exposed rock masses to a considerable degree. No instrumental measurement has ever been made concerning this point, but I very often have been suprised to experience unexpected heat in some deep valleys in spite of great altitudes. Is it not possible that the downsinking water on passing this heated zone may be heated more or less ?

IV. As to the source of the thermal water there is much to be investigated. If the heat source of the mountain hot springs really lies in the geothermal gradient, there must be hardly any trace of the so-called juvenile or magmatic water in the water of these thermal springs. It is believed that in most of the thermals in volcanic ragions the magmatic water occupies a variable proportion [12], although it seems to be no easy task to detect it precisely. Y. SHIBATA suggested the possibility of utilizing the heavy-water content of thermal waters as a means to determine the quantities of the magmatic water therein [3]. R NOMITSU, from his geophysical researches, concludes taat about one half of the total thermal water of Beppu Hot Springs, Kyusyu, is magmatic in nature [4]. Perhaps some minor constituents of thermal waters may in future prove to be useful in determining the proportion of the magmatic water included [5]. This method of scientific research on the spring waters of Taiwan is very much desired in order to prove or to disprove the downsinking theory, provided that the meaning of heavy water and minor constituents is valid.

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[1] S. KAWAMURA: Rep. Imp. Geol. Survey, Nos. 16, 30, 32 (1909, 1911, 1911), M. ISHIZAKI: Jour. Mining Inst. Japan, Nº 526 (1929), N.º 569 (1932).

[2] Neues Jahrb. f. Min. etc. B.-B. XXXVI (1911), pp. 107-157.

[3] Transactions, Japan Balneo-Climatol. Soc. *3* (1937), p. 79.

[4] Ditto, *4* (1938), p. 167.

[5] K. KIMURA: Trans., Japan Balneo-Climatol. Soc. *5* (1939), p. 3.

V. The significance of the geothermal gradient as the heat source of hot springs seems to have been ignored in our country , perhaps because we have been very deeply impressed with the volcanic activities which inevitably accompany thermal phenomena of various kinds. Volcanic heat is local and episodic, however , while the geothermal gradient is a universal phenomenon.

Subterranean heat increase is of course much more sudden generally in volcanic fields. Thus, ice-cold water in the crater at the top and almost boiling thermal water along the foot is a common feature everywhere. In such cases lavas and dykes may not be ignored as heat sources, but it should not always be considered that the old consolidated dykes and lavas directly heat the water which touches them. A geothermal gradient which is small should not be ignored as an important heat source even of volcanic fields.

Taihoku, July 29, 1939.

G. C. GEORGALAS
O. PROF. D. MINERALOGIE UND PETROGRAPHIE AN DER UNIVERSITÄT ATHEN

Die postvulkanische Fumarolentätigkeit und Wärmehaushalt des Santorin - Vulkans

(Mit 3 Tafeln)

Über die postvulkanische Fumarolentätigkeit und den Wärmehaushalt des Dafni - und Nautilus-Vulkanismus nach dem letzten epigenetischen Nautilus-Ausbruch, haben Georgalas und Liatsikas — auf Grund der von ihnen bis zum 2. VI. 1930 ausgeführten Beobachtungen — die bezüglichen Daten in folgenden Arbeiten gegeben :

« *Contribution à l'étude des éruptions 1925-26 et 1928 du volcan de Santorin* : Bull. du Comité Thalassographique Hellénique, Ann. 12, No. 1, 1932 ».

« *Die historische Entwicklung des Dafni - Ausbruches 1925-26 im Werke von* Hans Reck : *Santorin*, Bd. II, (siehe besonders Seiten 74-81 »).

« *Die historische Entwicklung des Nautilus-Ausbruches:* ebenfalls im vorgenannten Werk, Bd. II, Seiten 337-339 ».

Es wurde seitdem nichts bezüglich der Weiterentwicklung dieser Phänomene des Santorin-Vulkans bekanntgegeben.

Ich hatte immer die Absicht diese Phänomene systematisch zu verfolgen und habe zu diesem Zwecke am 1. VI. 1937 (jedoch nur während 3 - 4 Stunden) den Vulkan besucht ; letztens besuchte ich ihn wieder und weilte dortselbst vom 27. bis zum 29. V. 1939. Ich habe besonders während dieses letzten Besuches die bezüglichen Beobachtungen und Temperaturmessungen auf die hauptsächlichen, noch tätigen Fumarolen, sowie auf die in den kleinen Buchten der Laven hervorspringenden warmen Wässern und Gasen ausgeführt. Somit gebe ich heute einerseits ein

Bild der bisherigen Entwicklung der postvulkanischen Tätigkeit, sowie des heutigen bezüglichen Zustandes des Vulkanes und andererseits Daten für künftige Vergleichsbeobachtungen und Untersuchungen.

In den Tafeln I und II [1]) sind die hauptsächlichsten und interessantesten Fumarolen angegeben, die vom 27. bis 29. V. 1939 in Tätigkeit waren.

I. — **Fumarolen im Bereich des Ringwalles der Dafni-Kuppe.**

Innerhalb des Ringwalles steigen an kleinen Spalten und Oeffnungen des Bodens noch mehr oder weniger starke Fumarolen auf. Die in Tiefen von ca 15 bis 20 cm gemessenen Temperaturen gebe ich auf Tafel I an.

In einigen dieser Fumarolen vernimmt man mehr oder weniger deutlich den HCl-Geruch, wie zum Beispiel in den Fumarolen von 93°,4 (im Explosionstrichter g), 96° (mit weissen Sublimationen und Schwefelkristallüberzügen), 51° (mit gelbgrünen Ausblühungen und Wasserdämpfen), 80° (mit gelbgrünen Ausblühungen und Schwefelkristallüberzügen), 90° (mit gelbgrünen Ausblühungen), 137° (mit SO_2, Wasserdämpfen und Schwefelkristallüberzügen), 185° (mit braunen Eisenbeschlägen). Besonders deutlich ist aber der HCl - Geruch in den auf dem S - Rande des Ringwalles befindlichen Fumarolen von 74°, 152°, 161° und 150°, wo auch die gelbgrünen bis grünen Ausblühungen reichlicher sind.

In den Austrittstellen der Fumarolen von 167°, 285°, 295°, 110,° 106°, 108,° 210°, 122° und 72° - 58° werden braune Eisenbeschläge beobachtet, wogegen die Munde der Fumarolen von 112° und 72° - 58° auch mit Schwefelkristallen überzogen sind.

Ebenfalls die Fumarolen mit HCl und gelbgrünen Ausblühungen, die sich auf die Aussenflanken des SOlichen Sektors des Ringwalles befinden, sind noch am Werke mit Temperaturen von 70°,5 bis 86° Celsius.

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[1]) Als topographische Grundlagen für die Tafeln I, II und III wurden die entsprechenden Tafeln XCIII, CII und XCVII des 3. Bandes des Werkes: Hans Reck, *Santorin*, benutzt.

II. — Fumarolen im Bereich des Dafni-Zentrallavafeldes.

Diese Fumarolen werden auf Tafel II angegeben.

Bei einigen davon — wie zum Beispiel bei den Fumarolen von 87° und 90° sowie bei den Fumarolen von 45°-67° und 75°, die längs der Zerrungslinie $z' - z'_1$ heraussteigen — ist die Gegenwart von SO_2 an dem Geruch desselben merkbar. Die Munde dieser Fumarolen sind mit mehreren Schwefelkristallausblühungen überzogen.

Die Fumarolen hoher Temperatur, wie die von 233°, 308° - 344°, 285°, 235°, 171° und auch die von 124°, geben nur überhitzte Luft. Luft und Wasserdampf sind die Hauptbestandteile der Fumarolen von 55° (nordöstliche Flanken des Nautilus), 29°,2 - 34° (auf der nordöstlichen Randkante des Lavafeldes gegenüber vom Beobachtungsposten P_4).

Bemerkenswert ist eine neue Fumarole, die im Juni 1937 nicht vorhanden war und die an der NW-Ecke des Bodens des Explosionstrichters C mit einer Temperatur von $>$ 360° ausgetreten ist. Merkmale: überhitzte Luft, Eisenbeschläge und andere weisse Sublimationsprodukte um ihren Mund.

III. — Fumarolen auf den älteren Kuppen.

Auch auf den älteren Staukuppen (siehe Tafel II) kommt eine Fumarolentätigkeit vor. Es ist hierfür folgendes zu verzeichnen:

a) Auf den östlichen Flanken der Kuppe 1707 und etwas unter ihren Gipfelsaum Fumarolen mit vielen Wasserdämpfen, deren Abkühlung und Kondensation die Austrittsstellen der Fumarolen von fern sichtbar macht. Temperatur 55° Celsius. Ganz ähnliche Fumarolen gleicher Temperatur funktionieren auch auf den südlichen Flanken derselben Kuppe und etwas unter ihren Gipfelsaum; letztere haben weder während des Nautilus-Ausbruches noch während meines am 1. VI. 1937 Besuches funktioniert.

ORT	TEMPERATUREN:			Begleitende Erscheinungen:
	2. VI. 30	1. VI. 37	27.-29. V. 39	
Bucht T (zwischen der Küste von 1707 und den Liatsikas-Strom)	24°,5	—	23°	
Bucht L (Küste von Mikra Kammeni)	30°-32°	30°-31°	31°	Wenige H_2S-haltige Gasblasen. H_2S-Geruch. Sehr wenige Schwefelflocken.
Bucht M (zwischen der Stromzunge I a und den Laven von Mikra Kammeni)	42°-43°	42°-43°	43°-48°,1 *	Wasserströmung geht von einer heissen Quelle mit einer Geschwindigkeit von 0,23 m pro Sek. am Quellpunkt aus. Zahlreiche Schwefelflocken. Gasblasen. Starker H_2S-Geruch. Die Lavablöke des Strandsaumes mit einer dünnen Haut von gelblich-weissem Schwefel bedeckt.
Bucht A (zwischen I a un I b)	36°,5	—	?	
Bucht J (zwischen den Lavazungen II a und II b)	32°-32°,5	—	27°,8	Keine Wasserquellen, keine Gasblasen und Flocken.
Bucht N (zwischen der Küste von 1866-70 und der Zunge II c)	32°-34°,5	33°	36° *	Schwacher H_2S-Geruch am Eingang der Bucht und schwache Wasserströmung in ihrem innersten Teil. Wenige Gasblasen in weit auseinander stehenden Abständen. Wenige Flocken von kolloidalem Eisenhydroxyd und sehr wenige S-Flocken.
Bucht S (Südküste von Néa Kamméni)	(31. V.) 34°,5	—	28°	Sehr schwache Wasserströmung. Sehr wenige Eisenflocken.
Bucht G (Laven von 1866-70)	—	—	32°,2	Merkbarer H_2S-Geruch. Zahlreiche S-Flocken. Gasblasenaustritt im innersten Teil der Bucht.
Bucht R (im Hafen von Hagios Georgios)	42°	42°	42°	Schwache Wasserströmung. Wenige S-Flocken. H_2S-Geruch kaum merkbar. Rotgelbliche Färbung des Meerwassers der Bucht infolge einer Mischung mit Niederschlägen von Eisenhydroxyd.
Bucht Q (im Hafen von Hagios Georgios)	—	32°	32°,2	H_2S-haltige Gasblasen.

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* Die letztgemessene Temperaturen dieser zwei Buchten erscheinen jetzt etwas höher, weil die Messungen an weiter im innern gelegenen Stellen der Buchten vorgenommen wurden.

b) Auf der östlichen Oberkante der Georgios-Kuppe Fumarolen von 88° bis 90°.

c) In einem der Explosionstrichter des Gipfels von Georgios beobachtete ich eine Wasserdampffumarole von 42°,0 - 43°,5 Celsius, deren Mund mit Schwefelkristallen überzogen ist.

d) Auf der Mikra Kammeni-Kuppe bei P_4 eine Fumarole von 33°,4 Celsius.

IV. — **Hervorspringen von warmen Wässern und submarinen Gas-und Wärmequellen.**

Die Tafel III und die Tabelle I zeigen die in den innersten Teilen der kleinen Buchten der verschiedenen Lavazungen vorkommenden Hervorspringen von warmen Wässern, die submarinen Gas-und Wärmequellen, sowie die bezüglichen begleitenden Erscheinungen.

Wie aus vorhergegebenem zu ersehen ist, geht die stärkste Wasserströmung heute von einer heissen Quelle in der kleinen Einbuchtung M ab. Schwächer ist die Wasserströmung der Bucht R des Hafens Agios Georgios, wogegen die Einbuchtung J aufgehört und die der Bucht N sich in der Wasserlieferung und der Geschwindigkeit viel geschwächt hat. Ebenfalls viel schwächer in Bezug auf Wasserlieferung und Temperatur ist die Wasserströmung der Bucht S, die zuerst während des Nautilusausbruches aufgetreten ist.

Schlussfolgerungen.

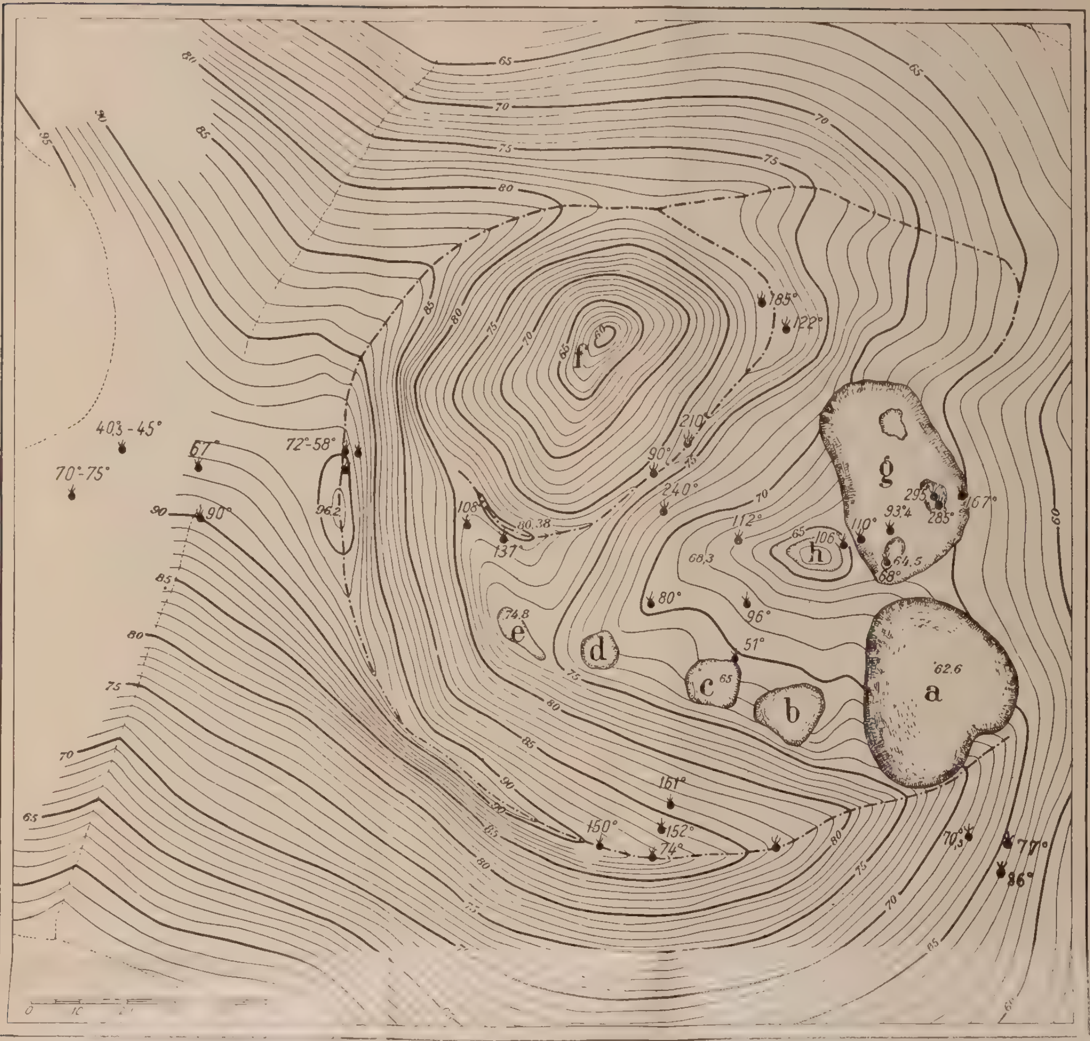
Aus vorhergegebenen Beobachtungen und Messungen ergeben sich folgende allgemeine Schlussfolgerungen :

1). Die postvulkanische Tätigkeit ist noch am Werke und äussert sich durch die subaerisch funktionierenden Fumarolen, der heraussspringenden erwärmten Wässern sowie der submarinen Gasaustritten. Von den Fumarolen funktionieren immernoch weiter alle drei Typen, die Georgalas und Liatsikas während des Dafni-Ausbruches (l. c.

Seite 78-79) erkannt haben, also Fumarolen, deren Temperatur über 300° umfasst, salzsaure Fumarolen von 100°-300° und Fumarolen des Temperaturbereichs bis 98°. Vertreter der ersten Type wurden nur in zwei Stellen bemerkt. Die Fumarolen der zweiten Type sind jetzt zahlenmässig viel weniger geworden im Vergleich mit der entsprechenden Zahl von Fumarolen dieser Type, die im Juni 1930 funktionierten.

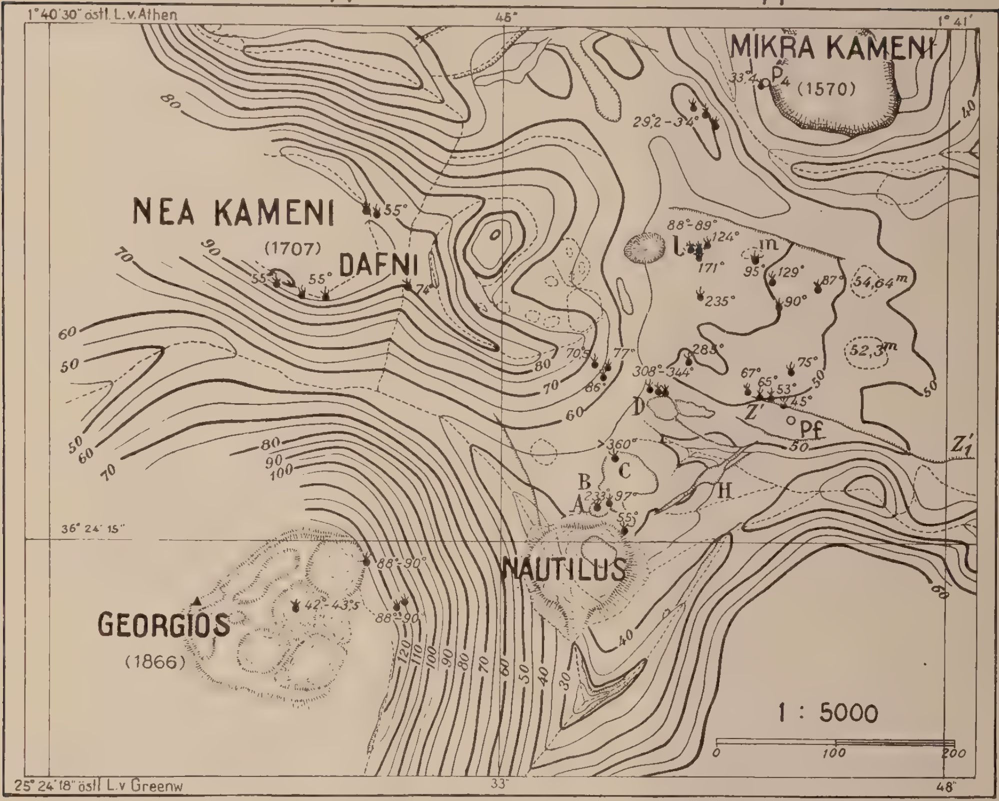
2). Aus dem Vergleich der heutigen postvulkanischen Tätigkeit mit der nach dem Ausbruch des Nautilus (Juni 1930), ergibt sich im allgemeinen, dass heute die Wärmezufuhr vom Vulkanherde in kleinerem Masstabe erfolgt als im Juni 1930.

Karte des Dafni-Kraters und Ringwalles



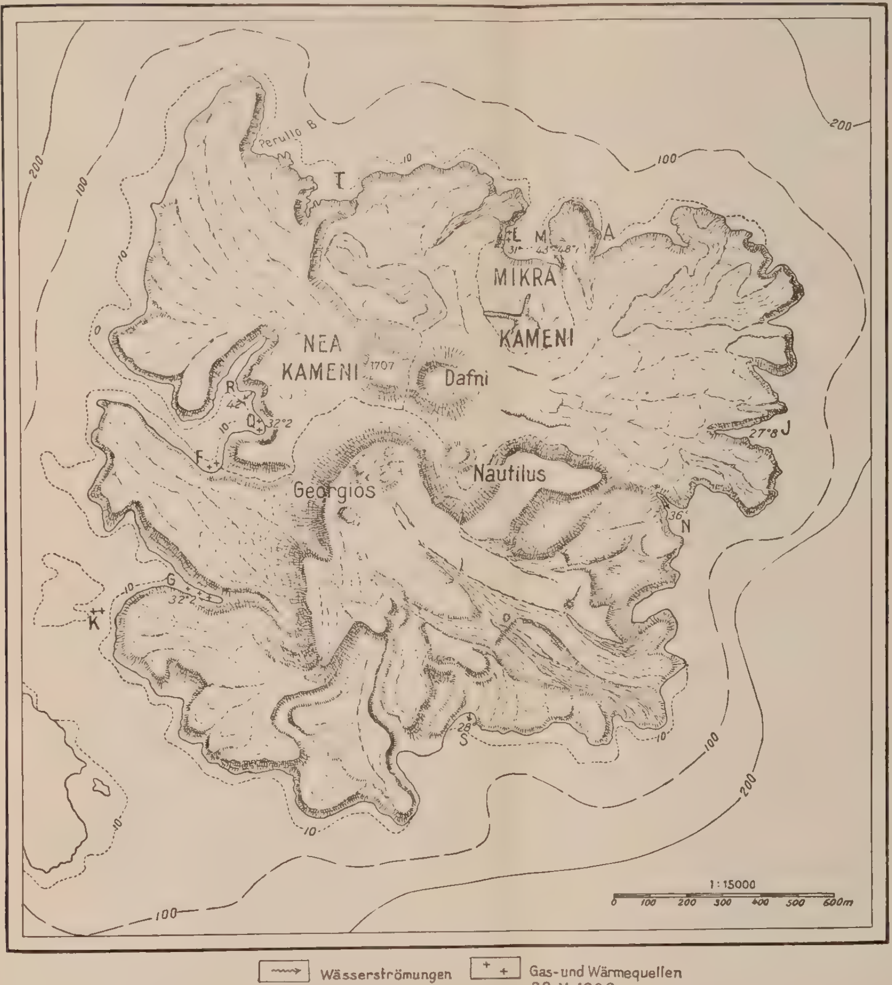
Die hauptsächlichen tatigen Fumarolen am 29. V. 1939.

Karte des Dafni-Zentrallavafeldes mit der
Nautilus Kuppe und den älteren Staukuppen.



Die hauptsächlichen tätigen Fumarolen am 27. V. 1939.

Übersichtskarte der Kameni Inseln



Temperaturmessungen vom 28.V.1939

CHRONIQUE DE L'UNION GÉODÉSIQUE ET GÉOPHYSIQUE INTERNATIONALE

INTERNATIONAL GEOLOGICAL CONGRESS
XVIII SESSION — GREAT BRITAIN, 1940

General Secretary:
GEOLOGICAL SURVEY AND MUSEUM,
EXHIBITION ROAD, LONDON, S. W. 7

REGISTERED TELEGRAPHIC ADDRESS

Inland Telegrams:
Incongeol, Southkens, London

Foreign Telegrams and Cables:
Incongeol, London

13th November, 1939

Dear Sir,

International Geological Congress

I am directed by the Council of the Geological Society of London and the Executive Committee of the Congress to request you to be good enough to insert the enclosed notice in the next issue of your Journal.

Yours faithfully,

General Secretary

. . . .

Signor **Francesco Signore**
Bulletin Volcanologique
Via Tasso, 199
Naples.

INTERNATIONAL GEOLOGICAL CONGRESS

The Geological Society of London announces that the XVIII Session of the International Geological Congress, which was to have been held in London from 31st July to 8th August, 1940, is postponed indefinitely.

OUVRAGES D'INTÉRÊT VOLCANOLOGIQUE

LACROIX, A. — **Le Volcan Actif de l'Ile de la Réunion et ses produits.** Un vol. in-8, de 297 pages, avec 68 planches et 1 carte. Gauthier-Villars, Editeur, Librairie du Bureau des Longitudes, de l'École Polytecnique, Paris, Quai des Grands-Augustins, 55, 1936. (Sans indication de prix).

SOMMAIRE. - *Avant-propos.* - Première Partie: *Description du volcan de l'Île de la Réunion et de ses environs* [par l'officier d'artillerie Alexis BERT]. *Vue générale sur la structure de l'île.* Deuxième Partie: *Le volcan actif.* Chapitre premier. *Morphologie et dynamisme.* I. *Vue d'ensemble sur le volcan actif.* II. *Le cratère central.* III. *Les fentes.* IV. *Les coulées.* V. *Fumerolles.* VI. *Tremblements de terre.* VII. *Succession des éruptions.* Troisième Partie. *Lithologie.* Chapitre premier. *Le volcan actif et ses enveloppes.* I. *Généralités.* II. *Le volcan actif.* III. *Les enveloppes du volcan actif. (Cônes interne et externe).* Chapitre deuxième. *Le Massif du Piton des Neiges.* I. *Observations préliminaires. Bibliographie du Massif.* II. *Roches volcaniques.* III. *Roches intrusives.* IV. *Sables magnétiques et titanifères.* Annexe. *Dépôt siliceux d'origine végétale (Mascareignite).* Chapitre troisième. I. *Comparaison de la constitution lithologique des deux massifs montagneux de l'île.* II. *Quelques notions sur la lithologie des îles Maurice et Rodriguez.* Appendice historique. *Les Observateurs du volcan dans le passé.* Supplément. *Nouveaux documents sur l'activité du volcan au XVIII^e siècle.*

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INHALT. - *Vorwort.* I. Teil: *Die ursprüngliche Lagerung der Gesteine.* II. Teil: *Tektonische Grundformen.*

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